4 (U.S. Geological Survey
Annual report
1894-95, pt 2)

ECONOMIC GEOLOGY

OF THE

MERCUR MINING DISTRICT, UTAH,

BY

J. EDWARD SPURR.

WITH INTRODUCTION

BY

S. F. EMMONS.

From Senator F. J. Cannon,
April 20, 1898.

CONTENTS.

ILLUSTRATIONS.

ECONOMIC GEOLOGY OF THE MERCUR MINING DISTRICT, UTAH.

By J. Edward Spurr.

INTRODUCTION.

By S. F. Emmons.

THE OQUIRRH MOUNTAINS.

TOPOGRAPHY.

From the base of the Wasatch Mountains on the east to that of the Sierra Nevada on the west stretches an arid region known to the early geographers as the Great American Desert, but more recently and accurately called the Great Basin, for the reason that it has no external drainage to the ocean. Geological investigation has shown that this region was once occupied by two large and distinct fresh-water seas, which have gradually disappeared by evaporation under the influence of slowly changing climatic conditions, until at the present day they are represented by relatively small saline lakes at the eastern and western extremities of the region, respectively.

The Great Basin has a physical structure peculiar to itself, consisting as it does of broad, nearly level valleys from 4,000 to 6,000 feet above sea-level, intersected by a series of narrow and often quite elevated mountain ridges, which trend with remarkable uniformity nearly due north and south. To these north-and-south ranges in the Great Basin, as well as to others in the similar region stretching southward beyond its limits through Arizona into Mexico, the name Basin ranges [1] has been given.

The Oquirrh Mountain range,[2] in which is situated the Mercur mining district, the subject of this report, is the first of these Basin ranges west of the Wasatch Mountains, from which its northern end is about

[1] G. K. Gilbert, U. S. Geological and Geographical Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1874, p. 22.

[2] The general structure of the Basin ranges may best be seen by reference to the atlas of the Geological Exploration of the Fortieth Parallel. That of the Oquirrh Mountains is shown on Map III of that atlas, and also on the Tooele Valley sheet of the Geologic Atlas of the United States published by this Survey. In the latter, by an error in copying, Ophir and Lewiston canyons are incorrectly represented.

15 miles distant and separated by the nearly level Jordan Valley. While from out the many canyon gorges that score the western flanks of the Wasatch Range flow considerable mountain streams, sometimes reaching rivers in size, which furnish the water for the irrigation ditches that have made of the eastern half of the Jordan Valley an almost continuous series of gardens and grain fields, the western half of the valley, as it slopes up toward the base of the Oquirrh Mountains, still has the arid character of the desert, and the moment the river is crossed the ubiquitous sage brush (Artemisia) becomes the prevailing plant, as it is throughout the extent of the Great Basin.

The great difference in amount of precipitation in the two ranges is due not to the elevation alone, for the average elevation of the Wasatch Mountains is scarcely a thousand feet more than that of the Oquirrh Mountains, but to the greater width of the elevated portion. In the Wasatch this width is about 25 miles, while the base of the Oquirrh Mountains from foothill to foothill is only 5 to 10 miles wide, and the median ridge is extremely sharp and narrow. Hence, only here and there are running streams found in the canyons of the Oquirrh Range, and these streams are generally too feeble to furnish water for irrigation purposes or for moving machinery. Like other Basin ranges, the mountains are characterized by relatively short, steep slopes, which descend almost continuously from summit to base without forming distinct foothills, such as characterize most great ranges. This is especially marked at the northern end, where they descend almost perpendicularly to the shore of Salt Lake.

The Oquirrh Mountains proper are only about 30 miles in length, but to the north, in the same line of elevation, is the partly submerged mountain ridge forming Antelope Island, and to the south a low ridge beyond Fairfield Pass connects them with the Tintic Mountains. At Tooele Peak, about 20 miles south of Salt Lake, the range, which thus far is extremely narrow, widens considerably and sends forth spurs at right angles to its main trend, which form transverse, east-and-west ridges extending partly across the adjoining valleys. On the east these form the Traverse Mountains, which separate Cedar and Utah Lake valleys on the south from Jordan Valley on the north; on the west they are continued in the Stockton Hills, which separate in like manner Rush Valley from Tooele Valley, but there is no stream of sufficient volume to break through the dividing ridge and connect the drainage of the two divisions, as does the Jordan River on the east. The southern third of the range is not only wider but more elevated than the northern two-thirds, and reaches its culminating point in Lewiston Peak (10,623 feet elevation), near its extreme end.

At this peak head two important ravines or canyons: Ophir or East Canyon, which runs west into Rush Valley, and Pole Canyon, which extends southeast into Cedar Valley near the town of Cedar Fort. Between these two are the less important Lewiston Canyon, south of and parallel to Ophir Canyon, at the head of which is situated the town and mining district of Mercur, and Fairfield Canyon, west of and parallel to Pole Canyon, in which are situated the Mercur mill and the branch railroad now building (1894–95) from Fairfield Junction on the Union Pacific Railroad (Tintic division) to the Mercur mine.

A line of depression, following the strike of a belt of soft, shaly beds, out of which Fairfield Canyon has been eroded, crosses the head of Lewiston and Ophir canyons, making very low passes between the three canyons. The Mercur mining district occupies the small basin thus formed at the head of Lewiston Canyon. The little town of the same name is situated in the bottom of the basin at the forks of the gulch, the narrow gorge below, which constitutes Lewiston Canyon proper, being cut through the harder limestones and sandstones that underlie the shale belt.

The general topographic structure of the region will be best understood by reference to the contour maps on Plates XXV and XXVI, the latter of which represents the Mercur Basin in detail; the former takes in the surrounding region, including Lewiston Peak and the southern end of the Oquirrh Mountains.[1]

ECONOMIC RESOURCES.

DISCOVERY AND DEVELOPMENT OF MINING DISTRICTS.

Although, according to Bancroft,[2] the existence of silver ores in the neighborhood of Great Salt Lake was known as early as 1857, the mining industry of Utah can not be said to have come into existence until 1869, when the advent of the transcontinental railroad and the consequent influx of Gentiles brought capital and enterprise to its aid.

The leaders of the Mormon Church had always opposed the development of mining by all the means in their power, fearing that the exciting and unsettling influence of that pursuit would turn away their

[1] As these maps were not prepared by members of the regular topographical corps of the Survey, it may be well to explain that the exigencies under which this work was undertaken rendered it necessary that the geologists should make their own topographical maps. The only instruments available were a small 14-inch plane-table, an alidade without telescope, an aneroid barometer, and an Abney level. Time also was very limited. The detailed map of the Mercur District was prepared by the writer, assisted by Mr. Spurr, the distance between two United States locating monuments, as given by the surveyors of Salt Lake City, being used as a base, and the elevation of the town above the Union Pacific Railroad at Fairfield Station being obtained from the engineers engaged in surveying the railroad line from that point to the Mercur mine. As the grading of this line was not completed until after field work was finished, it was not found practicable to represent it on the map.

The map on Pl. XXV was prepared later by using the Mercur map as a base and checking the distances from a triangulation made by Mr. Frank Anderson (of Palmer, Burton & Anderson, Engineers, Salt Lake City) to connect the Mercur, Glencoe, and Sunshine districts. The contours were sketched in on the plane-table by Mr. Spurr. It will not be surprising if maps made under such circumstances are not found to be absolutely accurate in every detail.

Our thanks are due to Mr. Anderson for copies of the underground maps of the Mercur and Marion mines, which he furnished to us with the kind permission of the owners of these properties, and which have been used by us in the preparation of various plates and sections; also to Mr. J. J. Hagerman for the hospitality extended in allowing us the use of his cottage as office and sleeping quarters, and to Messrs. James W. Neill, M. E., and A. E. Butts for valuable information with regard to the ore deposits of the region, with which they possessed much practical familiarity.

[2] History of Utah, by H. H. Bancroft, San Francisco, 1890, p. 741.

people from the more monotonous and peaceful occupations of agriculture, and thereby interfere with their great work of reclaiming the desert, and fearing, also, that the restless and sometimes rather lawless class of people who are attracted by mining excitements might prove a disturbing element in the population and tend to subvert their almost autocratic authority. This opposition, and the natural obstacles in the way of cheap mining or of an economic reduction of the generally rather refractory ores, acted as an effectual bar to the development or even the discovery of the mineral resources of the Territory in its early days.

It is to Gen. P. E. Connor, who commanded the California volunteers stationed at Fort Douglas, overlooking Salt Lake City, during the civil war, that credit is generally given for the first authentic discovery of silver ores in the Territory.

In 1863 General Connor found deposits of argentiferous galena at Little Cottonwood Canyon in the Wasatch Mountains, and on the west side of the Oquirrh Mountains, near the present town of Stockton. Others of his command discovered in the same year ores carrying lead and silver in Bingham Canyon, on the eastern slopes of the latter range, 20 miles southwest of Salt Lake City.

In December of the same year the West Mountain mining district was organized. It at first included the whole Oquirrh Range west of Jordan Valley; but later the western slopes were segregated under the name of the Rush Valley district, and the former name was retained for the eastern slopes, the working mines of which were confined practically to Bingham Canyon. Still later (1870) the western region was further divided into the Tooele, Rush Valley or Stockton, and Ophir or East Canyon districts.

In the Stockton district smelting furnaces were erected in 1864 by General Connor and his associates, and when at the close of the war the volunteer forces were disbanded, many of their members went into mining around Stockton, which gave to that town a fitful prosperity. With the failure of the smelting operations, which was a necessary result of the unfavorable economic conditions under which they were inaugurated, the district soon retrograded. In later developments the sanguine expectations of its discoverers have not been realized, though one mine has proved an important and heavy producer. Some exceptionally rich ores were found in Ophir Canyon, and the discoveries extended into the neighboring districts. Dry Canyon on the north and Lion Hill on the south formed part of the Ophir district; the indications of ore were traced still further south from the latter point, and in 1869 a small mining camp, called Lewiston, had already been started in the canyon of the same name, about 4 miles due south of Ophir. As the inhabitants drew their supplies of food largely from the neighboring settlement of Camp Floyd, the district was generally known as the Camp Floyd district.

Twenty miles further south, beyond a gap in the range known as Fairfield Pass, through which the railroad now runs, is another group of hills in the same line of elevation as the Oquirrh Mountains, but of less regularity of structure, known as the Tintic Mountains. Ore bodies were discovered on the western side of these hills in 1869, the first vein opened being the Sunbeam; the now famous Tintic mining district was organized in the same year, and has since become one of the most important producers in the Territory.

After the completion of the transcontinental railway, in the spring of 1869, the discovery of the great body of rich silver ore in the Emma mine at Little Cottonwood Canyon, from which over $2,000,000 was taken, and the building of large smelting plants along the railroad south of Salt Lake, which afforded a market for the refractory ores of the region, gave an immense impulse to prospecting and mining throughout the Territory. Within a comparatively few years mining districts sprung up and valuable mines were developed at widely distant points, and the Territory took rank as an important producer of the precious metals, especially of silver. Since 1880 it has ranked third among the States and Territories as a producer of silver, but its gold product has been of much less importance, and in the production of this metal it has held only the eleventh place. Hence a source of increase in the production of the latter metal, especially since the great decline in the price of silver, would prove most important to the mining community of the Territory, and it is partly for this reason that so much interest has been excited in the little mining district of Mercur.

Since 1869 railroad facilities have enormously increased, so that the cost of mining, and, what is even more important, of bringing the product of the mines to market, has been greatly diminished. A narrow-gauge railroad now runs from Salt Lake City around the northern point of the Oquirrh Mountains to Tooele and Stockton. A branch of the Rio Grande Western Railroad connects the mines of Bingham Canyon with the principal smelters at Sandy, south of Salt Lake City. Branches both of the Rio Grande Western and of the Union Pacific have been built to the Tintic mining district, the former entering it from the east, the latter from the west. A short branch of the latter road, completed since the present work was undertaken, connects the mine of Mercur with its mill in Fairfield Canyon and with the Union Pacific line at Fairfield station. The grades on all these roads are low for a mountainous country, and coal is produced abundantly in the Territory by mines situated along the eastern flanks of the Wasatch uplift, both to the northeast and the southeast of Salt Lake City. The conditions would therefore seem to be favorable for the development of an important and permanent mining industry, for experience has shown that the mountains abound in rich mineral deposits, and that a great many instances of unsuccessful mining are to be attributed to ignorance or incompetence of the management rather than to failure in the quality or quantity of the ore.

PRODUCTION OF MINING DISTRICTS.

The relative economic importance of mining districts is necessarily gauged by the values of their products, though there may be other qualifying circumstances in special cases that produce valid exceptions to the rule. Hence the following table of the production of the several most important mining districts of the Oquirrh Mountains has been prepared for purposes of comparison. The material has been largely compiled from the reports of the Commissioner of Mining Statistics (1870–1876) and from those of the Director of the Mint (1881–1893), and though necessarily incomplete, the figures represent approximations that sustain a uniform proportion one with another, and hence are valid for comparative purposes.

Production of Oquirrh mining districts to Jan. 1, 1894.

District.	Gold.	Per cent.	Silver.	Per cent.	Aggregate coinage value.	Per cent.	Lead.
	Ounces.		*Ounces.*				*Tons.*
Tintic	127,000	47.8	18,866,000	54.00	$27,017,080	54.00	66,000
Bingham	113,000	42.5	12,690,000	36.35	18,742,818	37.00	250,000
Ophir	5,600	2.2	2,780,000	8.00	3,490,231	6.90	49,000
Stockton	1,000	0.4	520,000	1.52	692,980	1.30	1,000
Camp Floyd	19,000	7.1	46,000	0.13	452,238	0.80	....
Total	265,600	......	34,902,000	......	50,395,347	......	366,000

The first shipment of ore from the Territory was from Bingham. According to Bancroft[1] this shipment consisted of a car load of copper ore that in June, 1868, was hauled by wagon to the Union Pacific Railroad at Uinta and forwarded by Walker Bros. to Baltimore, Md.

Bingham Canyon is also the only district in Utah where placer mining has been carried on with profit to any considerable extent. It is estimated that in the first five years, commencing with 1868, 5,000 ounces of gold per year were obtained from it. After that placer mining was neglected, owing to the growing importance of silver-lead ores. From scattering and not always accurate sources of information its total production of placer gold has been estimated in round numbers as 40,000 ounces. The other gold given in the table above is from deep mines, the values from some of which are largely in this metal.

Recent deposits of oxidized copper ore are also found in the detrital material of the canyon, and it was from them that the shipment mentioned above was probably made. The deposits are evidently formed by the leaching of copper ores below the surface, yet no copper minerals are said to be found in the ore bodies until considerable depth is reached. The succession of minerals in depth is said to be, first, a zone carrying zincblende and galena in about equal proportions; then a zone with galena and zincblende in the proportion of about 4 to 1; then a zone of iron pyrite, and below this a mixture of copper pyrite.[2]

[1] History of Utah, by H. H. Bancroft, San Francisco, 1890, page 741.
[2] Personal communication from A. F. Holden.

Bingham has been a large producer of lead ores, and the estimate gives an aggregate of about a quarter of a million tons of this metal as its total yield.

Its silver production increased steadily from about 65,000 ounces in 1871 to nearly 1,000,000 ounces in 1879, which is the maximum annual production. It has since varied with the economic conditions. The present annual production is about 600,000 ounces of silver and 7,000 ounces of gold.

The production of Ophir began to assume importance in 1870. The ores were very rich; some from the Mono mine are said to have contained 50 per cent of silver, and small shipments from the Silveropolis to have averaged over $6,000 per ton in 10-ton lots. In its palmy days its annual product probably amounted to over half a million ounces of silver, but its rich bodies were soon exhausted, and the camp suffered a relapse much earlier than did Bingham. For 1893 its product is estimated at about 150,000 ounces of silver and 400 ounces of gold. Its ores carry a much smaller proportion of lead than those of Bingham, and the total production of this metal in the district is estimated at less than 50,000 tons.

The production of the Stockton district has extended over a longer period than that of either the Ophir or Bingham, but has been very irregular, and, as shown by the table, is very much less in aggregate amount.

Still less important has been the Camp Floyd (or Lewiston) district. During the ten years from 1871 to 1881 it has probably produced about 46,000 ounces of silver, which is the total mineral production of the camp for that time, since the ores then worked contained no lead, copper, or gold. The gold production of its successor, the Mercur district, which became important in 1892, amounted in that and the succeeding year to about 19,000 ounces, and as the gold ore is quite free from silver and lead, this is also the total production of the camp for that time.

Tintic district, in 1871, produced about 26,000 ounces of silver, and developed but slowly during the time when Bingham and Ophir were enjoying their greatest prosperity. The advance in its production was, however, very steady and persistent up to the time of the great drop in the price of silver. Its maximum product was probably the yield of 1890, which is estimated at 3,800,000 ounces of silver and 24,000 ounces of gold. The product for 1893 was about 1,900,000 ounces of silver and 15,000 ounces of gold. Copper is an important constituent of some of the ores, but it is especially difficult to arrive at accurate estimates of the amount produced, as it is generally shipped to distant smelters. It is roughly estimated that 15,000 tons of this metal have been produced in the district.

If Tintic be considered as one of the Oquirrh Mountain districts—and geologically it undoubtedly should be—the mineral wealth of this range has proved itself of equal if not of greater importance than that of its far greater neighbor, the Wasatch Range, and together, at the present day, these furnish over two-thirds of the precious-metal product of the Territory.

If the metals are considered separately, it is to be noted that the total silver production of Utah for 1893 was about 6,358,000 ounces, of which the Oquirrh districts produced 2,707,000 ounces. The total gold production, on the other hand, for the same period, was about 42,000 ounces, of which the Oquirrh districts produced 38,000 ounces.

In estimating the commercial value of this product, with gold at $20 per ounce and silver at $0.73 per ounce, the total value of the Oquirrh ores for 1893 was $2,736,100, while that of the ores from the rest of Utah was $2,745,230; so that, considered in this way, the Oquirrh districts have furnished half the precious-metal product of the Territory.

CAMP FLOYD OR MERCUR MINING DISTRICT.

Although the town of Lewiston was already established as a mining camp in 1869, but little prospecting seems to have been done until 1870 or later.

The following is the first notice of the district that appears in print:[1]

Camp Floyd district.—This district adjoins Ophir or East Canyon district on the south. It is comparatively new and the claims are not yet much developed. The outcroppings of veins are well defined and are not so high up on the mountain as at Lion Hill. The winters are not so severe, and it is claimed that miners can work in open claims during the season. Among the principal claims are the Sparrowhawk, Silver Cloud (reported to have been recently sold to an English company), Mormon Chief, and the Grecian Bend. There is also a vein affording cinnabar of low percentage.

Sparrowhawk.—This claim, opened during the summer by Mr. McMasters, shows a considerable body of shaly quartz of a dull, bluish-gray color, and coated with films of chloride of silver. The vein is marked by very heavy quartz croppings. The thickness at the open cut, from which most of the silver-bearing ore has been taken, is about 50 feet, but it is irregular. A large portion of these croppings is apparently quite free from ore in paying quantity. In August last year there was a large pile of ore on the dump, estimated at 100 tons of first-class and the same quantity of second-class ore.

Grecian Bend.—This claim is a short distance beyond the Sparrowhawk and may be a prolongation of the same vein. This and the Mormon Chief claim beyond it are adjoining claims, each having 2,000 feet upon the lode. They are characterized by an enormous outcrop of quartz, stretching up the side of the mountain for a mile or more. It rises from 20 to 50 feet or more in height, and has an irregularly broken, precipitous face. It pitches into the hill at an angle of about 20°, and the general direction of the cropping is 10° south of west. This outcrop is in general quite hard and compact, and gives little indication of being ore bearing, though the color is dark, and it much resembles the quartz at the Sparrowhawk claim, where chloride of silver has been found. Very little work has been done on either of these claims. With the exception of two small pits upon the lower edge of the cropping, the mass of the vein is untouched and awaits vigorous work, conducted upon a liberal scale, to break into the rocky mass and show whether it is ore bearing or not. At one of the excavations there are some small streaks of ore, which, it is said, assay well for

[1] Mineral Resources west of Rocky Mountains for the year 1871, R. W. Raymond, Washington, 1873, p. 313.

silver. At that place the ledge appears to be split up into several layers, but all of them are conformable to the strata of shaly limestone above and below. The indications are sufficient to justify the expenditure of some money in prospecting the ground, especially along the contact of quartz with the wall rocks.

In the same reports, for the year 1872 (p. 255), it is said that an English company which had acquired the Sparrowhawk, Last Chance, and Marion mines had worked them actively, employing 40 to 50 miners, and that the company had also built a 20-stamp mill, capable of reducing 30 tons of ore per day. The developments of free-milling ore in the Mormon Chief, Grecian Bend, Silver Cloud, Star of the West, Stafford, Carrie Steele, and other mines are also spoken of in the most encouraging terms, and a second stamp mill is said to have been recently completed at Fairfield.

The United States report on Mineral Resources for the year 1873 (p. 276) notes that the mill of the English company had ceased running on its own ores, because "they are very difficult to assort, and of too low grade to pay for extraction without sorting." In the description of the mineral composition of the ores no mention is made of the antimony with which they are impregnated, nor of the possibility that it may have been the presence of this metal that interfered with the amalgamation. The mill worked during the year mainly on custom ores, and it is said to have produced, up to the end of November, 56 bars of bullion, worth over $52,000, while the tailings on hand were worth $40,000. The camp probably reached its maximum production of silver during this year (1873), for which 11,000 ounces are reported. In 1874 the mining operations are reported to have been unimportant; the mill was running on custom ores.

For the next seven or eight years a small but somewhat continuous production of silver is reported, probably obtained from small bodies of chloride ore near the surface. The average annual output of the camp during the period of its former activity may be estimated at about 4,000 ounces.

Early in the eighties the camp became almost entirely deserted, and of the town of Lewiston only a house or two remained. So completely was it forgotten that the name was given by the postal authorities to another town in Cache County, Utah, and when mining revived, some ten years later, a new name had to be given to it.

The mines mentioned in the above reports are the silver mines, which are now completely abandoned. The projecting outcrop of dark, siliceous rock in which the silver ores were found still goes by the name of the Silver ledge. The occurrence of gold, which constitutes the present value of the camp, was not mentioned in the above-quoted reports, although it is evident that the gold-bearing ores were noticed by the early explorers.

The report on Mineral Resources for 1873 has the following:

In Camp Floyd several deposits of cinnabar have been discovered. On the Jenny Lind an incline 50 feet deep has been sunk. Experiments made with several hundred pounds of ore gave the average percentage of quicksilver in the assorted stuff as 4 per cent. The New Idria is located on the same vein as the one just mentioned. In a 20-foot incline sunk on it 4 feet of ore are reported to be exposed. It has the same value as that from the Jenny Lind.

From this and the mention in the quotation from the report for 1871 of a "vein affording cinnabar of low percentage," it is evident that what is now known as the Gold ledge, which is but a hundred feet or so above the Silver ledge, had been remarked, but its gold contents had evidently not been suspected. This is hardly surprising, considering the usually low percentage of this metal, and the fact that it is never visible in the ores, even with the aid of a glass.

About 1890 interest in the camp was revived through the discovery that at an horizon about 100 feet above the Silver ledge, or stratum from which the antimonial silver ores of the early days had been extracted, a line of decomposed ocherous-looking rock, often stained red by cinnabar or realgar, carried a small but very persistent percentage of gold. The old and generally abandoned claims were bought up and consolidated into several groups. The most important company of the present day had a number of claims on the south side of the ravine immediately above the site of the old town. One of these claims was called the Mercur, probably on account of the occurrence of cinnabar, or mercuric sulphide, on the outcrop of the Gold ledge within its limits. From this the company and the little town that soon grew up derived their names.

The managers of the Mercur Company for some time found considerable difficulty in devising a process which would reduce their ore at a profit. It was of too low grade and too free from fusible metals, like ead, to be profitably smelted. Repeated attempts at amalgamation were unsuccessful, and it is said that in the mill at first erected to treat the ores they yielded less than the amount of the running expenses. Successful experiments were finally made with the MacArthur-Forrest cyanide process, which dissolves the gold in a solution of cyanide of potassium, from which it is precipitated by peculiarly prepared shavings of metallic zinc.

On account of the scarcity of water the leaching mill was not erected in Lewiston Canyon, near the mine, but in Fairfield Canyon, 3 or 4 miles distant, and half way to Fairfield Station. Here a spring furnishes a fine flow of water from a bed of shale at the base of the alternating siliceous and calcareous strata which are folded into a syncline in the bed of Pole Canyon.

In this mill the treatment of the ore, which is little else than a decomposed limestone or porphyry, has proved most successful. In practice it is very coarsely crushed for leaching, so that the tailings are large pieces of rock about half an inch in diameter. Hence, in spite of the expense of hauling the ores on poor roads over the divide separating the two canyons, they have paid very generously to their owners.

In 1892 the Mercur mine produced upward of 4,000 ounces of gold,[1] and up to November, 1894, the company had paid $175,000 in dividends.

In 1893 the Marion mine, formed by the consolidation of the Sparrowhawk, Marion, and other claims which in former days had been extensively worked for silver, became productive. Its workings are situated on the north side of the gulch directly opposite the claims of the Mercur mine, and the spurs on which these two working mines are located are known from them as Mercur and Marion hills respectively. At the east foot of Marion Hill, and just north of the town, a mill was built for treating the ores of the Marion mine by the cyanide process. This mill has been running successfully ever since, and, it is claimed, can profitably treat an ore carrying only $4 in gold per ton. Water for the mill is obtained from the Sparrowhawk spring, with which it is connected by about 2 miles of pipe. The Sparrowhawk spring is situated on the same belt of water-bearing shale as the Mercur spring, but several miles to the northwest, near the summit of the divide over which the road from Mercur to Ophir passes.

The production of the district for 1893, which is the combined product of the Mercur and Marion mines, was between 14,000 and 15,000 ounces of gold.

In the summer of 1894 the Geyser Company, whose claims are situated on the northeast side of Marion Hill, commenced work upon another cyanide mill, situated a few hundred yards above the Marion mill. This was finished too late in the season to permit of much production. The scarcity of water is a decided obstacle to milling in the canyon, for there is no running water, and the known springs have a limited supply of water and are all taken up. There are two water-bearing belts that cross the canyon, which are indicated on the accompanying geological map (Pl. XXVI). On the upper of these belts are the Mercur, Sparrowhawk, and Franklin springs; on the lower the Silver Cloud and Surprise springs are the only ones that have yet been developed.

At the time of examination (October–November, 1894) the grading of a branch railroad destined to connect the Mercur mine and mill with the Union Pacific Railroad at Fairfield junction was nearly completed. It is to be expected that with the completion of this railroad some of the other claims may be more vigorously explored for deposits of gold-bearing ore and be eventually added to the list of producing mines.

[1] Production of gold and silver in the United States for 1893, by the Director of the Mint, Washington, 1894, p. 113.

GENERAL GEOLOGY.

STRUCTURE.

The only geological investigations made of this range have been in the nature of reconnaissances, and were conducted by the earlier exploration parties about twenty-five years ago. As geologist of the Wheeler survey, Mr. G. K. Gilbert,[1] in the years 1871 and 1872, and Mr. E. E. Howell,[2] in the years 1872 and 1873, visited portions of the Oquirrh Range, and in the summer of 1869 the writer, as one of the geologists of the Fortieth Parallel Survey, traversed the range from north to south. The following extract from his report[3] gives the general features of its structure, as then determined:

> They [the Oquirrh Mountains] are composed mainly of Carboniferous limestones and quartzites, which the forces of contraction, acting almost equally in either direction, have compressed into a series of complicated folds, in which the prevalent strike, however, is in a northwesterly direction. The folding of these beds has been accompanied by a very considerable metamorphism and by the injection of porphyritic dikes, together with subsequent mineralization in the more disturbed districts.
>
> The southwestern portion of the range, to the west of the main ridge, is a quaquaversal uplift in the Wasatch limestone, in the center of which, at Ophir City, a faulting at right angles to the longer axis of the uplift has brought up the upper beds of the Cambrian. From Ophir City as a center these limestone strata all dip away—steeply toward the west, more gently toward the north, east, and south.
>
> The main crest of the range between Tooele and Lewiston peaks is the remnant of the flat arch of an anticlinal fold, which descends both to the north and to the south, resulting at the south point of the range in two minor synclinal folds, in Pole Canyon and in the canyon south of Lewiston, and a similar synclinal fold to the north in the region between Soldier Canyon and Tooele Canyon. In the region between Tooele Peak and Connor Peak, more particularly in Bingham Canyon, which is almost entirely in the beds of the Weber quartzite, the structure lines are much more difficult to follow, and evidently the general system of folding observed in the southern portion is much complicated by minor folds; but its structure is in general that of a synclinal fold in these beds, while at the northern point of the range, beyond Connor Peak, the beds of the Lower Coal Measure group are found to be pushed up and crumpled together in short, sharp folds, giving, in an east and west section across the northern point, no less than three small anticlinals, while the tendency of all the beds is to dip steeply beneath the waters of the lake.

With regard to this northern portion of the range, there is still much obscurity, the time available for the earlier examinations having been too limited to admit of the satisfactory working out of its complicated structure. Mr. Gilbert[4] suggested in his report that the abrupt termination of the northern end of the range and the steep dips of its strata are due to faulting. Good ground for such an assumption may be

---

[1] U. S. Geological and Geographical Surveys West of the One Hundredth Meridian, Vol. III, Geology, Washington, 1875, p. 25.

[2] Ibid., p. 237.

[3] U. S. Geological Exploration of the Fortieth Parallel, Vol. II, Descriptive Geology, Washington, 1877, p. 443. See also Vol. 1, Systematic Geology, p. 736, and analytical geological map x.

[4] Op. cit., p. 26.

found in the topographic form of the northern spurs, a portion of which is well shown in the frontispiece of his admirable memoir[1] on the Pleistocene phenomena of the eastern half of the Great Basin, or the Lake Bonneville region.

With regard to the southern portion of the range, the description above quoted is essentially correct. South of Tooelė Peak the range consists of two great anticlines with an included synclinal fold, the trough of the latter occupying the depression of Pole Canyon. The axes of these folds have a direction N. 25° to 30° W., or about 30° more to the westward than the crest of the range, and all three appear to pitch downward both northwestward and southeastward from about the line of Ophir Canyon. Hence, the western anticline, which forms the projecting southwestern portion of the range and which was the subject of study in the present investigation, is an elongated quaquaversal, with the center of the arch, where the lowest beds are exposed, at Ophir Canyon. The axis of this fold runs very near the western foothills of the range, so that while at these foothills the dip of the beds is strongly toward the valley from Stockton round to Fairfield Pass, by following up any of the western canyons one comes, within a mile or two from its mouth, to beds dipping easterly, or into the range and away from the valley. In all these folds the dip of the beds grows steeper as the distance from the axis of the fold increases, and in a broad way the eastern sides of the anticlines are the steeper, the angles of dip reaching 60° to 70°.

Faulting in this portion of the range has been an extremely subordinate phenomenon as compared with plication, the fault in Ophir Canyon being the only one observed in which there was a large displacement of the adjoining beds.

SEDIMENTARY ROCKS.

The exact geological horizon of the beds forming any of the Basin ranges is always difficult and often impossible to determine, since they are completely isolated by the more recent valley deposits, which occupy about two-thirds of the aggregate surface and so effectually conceal both form and character of the rock surface beneath that it is impossible to establish a stratigraphical connection or valid correlation with the beds of the nearest ranges. The parts of these ranges now exposed to observation are in reality only the upper and steeper portions of mountain masses of more than double their basal width.

Although fossils are comparatively abundant in the rocks of the Oquirrh Range, with the exception of a few Cambrian forms obtained from the quartzite and shales of Ophir Canyon, most of those collected thus far have been of types that range from the bottom to the top of the Carboniferous. Hence, in establishing probable horizons to correspond with those of the type section in the Wasatch Mountains, it has

[1] Lake Bonneville, Mon. U. S. Geol. Survey, Vol. I, Washington, 1890.

been necessary to base the determinations largely on general sequence of conditions of sedimentation.

The thickness of the members of the Paleozoic column, as recognized in the Wasatch Mountains by the geologists of the Fortieth Parallel Survey, was, in round numbers, as follows:

Paleozoic section in the Wasatch Mountains.

System.	Formation.	Average thickness.
		Feet.
Carboniferous (15,000 feet)	Upper Carboniferous limestone (including Permian.)	2,500 to 3,000
	Weber quartzites, with a few thin beds of limestone.	5,000 to 7,000
	Wasatch limestone (with Waverly and Devonian fossils at the base).	7,000
Devonian (2,000 feet)	Ogden quartzite	1,000 to 1,250
Silurian (1,000 feet)	Ute limestone	1,000 to 1,250
Cambrian (12,000 feet)	Big Cottonwood quartzite series (clay-slates at top).	12,000
	Total, about	30,000

Of these formations, only the Cambrian quartzite, Wasatch limestone, and Weber quartzite have been definitely recognized in the Oquirrh Mountains, no fossils of Permo-Carboniferous, Devonian, or Silurian types having yet been discovered. Still, it can not be safely assumed that these formations are not represented until a more exhaustive search for their fossils has been made.

In the Cottonwood region of the Wasatch Range, and northward from there, the lithological separation of Weber quartzite from Wasatch limestone is sharp and distinct, the one being almost as free from limestone as the other is from siliceous beds. To the southward, however, in the Timpanogos Peak region, the upper part of this great limestone zone consists of a series of alternating beds of quartzite and limestone, which were called the Intercalated series, and which probably in part represent the Weber quartzite.

In the Oquirrh Mountains the Weber quartzite was supposed, in the earlier explorations, to be typically developed in Bingham Canyon, where the formation is predominantly quartzitic. There, according to Mr. A. F. Holden, who has had opportunities of studying the series in detail, it consists, in round numbers, of 500 feet of shales and 350 feet of limestone, in beds 50 to 100 feet thick, interbedded with quartzites, forming an aggregate thickness of 6,700 feet of rock strata. These beds belong to the eastern member of the eastern anticline, and corresponding beds will probably be found in the upper part of the trough of the Pole Canyon syncline.

On the west side of the range, Mr. Spurr has carefully measured the section of the western anticline exposed by the erosion of Lewiston Canyon, and finds about 12,000 feet of beds from the lowest point under the crest of the anticline up to the top of the ridge dividing the head of Lewiston Canyon from Pole Canyon. Of these the lower half is mostly of limestone, and the beds carry Lower Carboniferous fossils, while the upper half, which consists of alternating beds of limestone and of calcareous sandstone that has the outward appearance of quartzite, carries Coal Measure or Upper Carboniferous forms.

Inasmuch as the Coal Measure forms in this region extend both above and below the horizon of the Weber quartzite, and have a vertical range of 10,000 to 15,000 feet, it is necessary to depend largely upon lithological characteristics and stratigraphical data for the determination of horizons. When, as in this case, the detailed examination has not been extended completely across the range, correlation of beds as widely separated as are these from the beds of Bingham Canyon must be somewhat hypothetical. It seems probable that these upper beds, the Intercalated series of Lewiston Canyon as they have been called, correspond to the upper part of the Wasatch limestone as developed in the Cottonwood region, and belong below the Bingham Canyon beds.

The Lower Carboniferous limestones of Lewiston Canyon constitute the ore-bearing horizon of the Mercur district. Above them, and yet beneath the more siliceous beds of the Intercalated series, are beds of clay-shales, thus showing a sequence of general conditions of sedimentation (from calcareous, through argillaceous, to siliceous beds) similar to those which so generally prevailed at these horizons throughout the Rocky Mountain region of Colorado. A second series of siliceous beds, about 600 feet in thickness, occur near the base of the Lewiston Canyon section, and it was at first thought that these might correspond to the Ogden quartzite of the Wasatch section; but Lower Carboniferous forms were found both in and below them. Hence the base of the Wasatch limestone is not exposed in this canyon.

On the north side of Ophir Canyon, and a few hundred yards north of its bed, a peculiar arch of Cambrian quartzite has been uplifted by the throw of a fault running parallel to the course of the canyon and at right angles to the axis of the anticline. Above the quartzites on the north side of the canyon are characteristic greenish clay-slates, carrying primordial trilobites, and back of these again rise 2,000 feet of limestone cliffs, in which sub-Carboniferous or Waverly fossils have been found near the top of the wall. On the south side of the canyon a still steeper wall of limestone, 2,000 feet in height, forms the northern face of Lion Hill. Near the summit of this hill is an ore-bearing zone that probably occupies very nearly the same horizon as that which is known in Lewiston Canyon as the Silver ledge. If this assumption be correct, the base of the south wall of Ophir Canyon is at least 1,000 feet lower in horizon than the lowest beds exposed in Lewiston Canyon.

What the throw of the Ophir Canyon fault is can not be definitely settled until the faunal correspondence of given horizons on either side of the canyon shall have been more accurately determined. From present knowledge it is probable that it may amount to 1,000 or 2,000 feet. Ore deposits have been opened on the north side of the fault in the Lower Carboniferous beds of Dry Canyon, and from there downward to the shale beds, just above the fault, which separate the limestones from the underlying Cambrian quartzite; while on the south side they are mainly confined to the beds near the top of Lion Hill. Hence it is apparent that there must have been other causes beyond and independent of the geological horizon of the beds that have influenced the deposition of ore within them.

IGNEOUS ROCKS.

In the Fortieth Parallel report already quoted a connection was suggested between the occurrence of igneous rocks and ore deposition, and later investigations in various parts of the Cordilleran region have not only shown such a connection to be very general and widespread but have indicated that in many cases the connection is more than a coincidence and probably has a genetic basis.

In the Oquirrh Mountains there are no large exposures of eruptive rocks such as result from surface outflows, except possibly on the extreme eastern spurs near the Traverse Mountains. The bodies that had hitherto been observed, as well as could be determined from the generally altered and rather obscured condition of their outcrops, were dikes and irregular intrusive bodies or stocks. In Bingham Canyon it is said to be a matter of common observation that the ore is found only in the vicinity of one of the bodies of porphyry that occur there.

The present investigation has shown that the porphyries found in the Mercur district occur not only as dikes and stocks, but largely as thin sheets, generally parallel to the stratification; and it is immediately beneath certain of these sheets that the principal ore deposition has taken place.

There are two varieties of porphyry in this district, one of which, the Eagle Hill variety, is very like the White porphyry of the Leadville district in internal structure; the other, here called the Bird's-eye porphyry, is more like the Gray porphyry of Leadville. Both varieties occur as intrusive sheets spreading out between the strata, with which they preserve a general parallelism, though at times they cross at a low angle from one bedding plane to another. The vents or channels through which the magma that formed these sheets was forced up from below are not sufficiently exposed by erosion to admit of their being exactly located, but such evidence as is available shows that they are probably in a general zone running parallel with the strike and on the east side of the axis of the anticline. Actual dikes crossing the strata at right angles were observed only in the case of the Bird's-eye porphyry at the head of Silverado Canyon. This variety has been traced from the northern edge of Mercur Basin nearly to Ophir, and is probably the same rock that forms the dike-like wall projecting from the limestone cliffs on the north side of Ophir Canyon. The Eagle Hill porphyry finds its greatest development on the southern edge of the Mercur Basin, around Eagle Hill, and it is probable that the channel through which it was forced up is somewhere in this vicinity. From here it has been traced southward nearly to the end of the range, and northward across the Mercur Basin to Lion Hill, thus overlapping the Bird's-eye porphyry at a slightly lower horizon.

As regards the age of these rocks, it can only be said with certainty that they are older than the Pleistocene and younger than Carboniferous rocks, for there are no rocks of intermediate age in this region that will serve to fix the time of eruption more closely. It is probable that they were intruded into the sedimentary strata before the latter were plicated, for it is difficult to conceive that the molten rock could have followed the bedding planes so closely as it did after they had been folded into anticlines and synclines, and necessarily more or less broken and displaced. Moreover, the porphyry is faulted with the strata in the minor fracturing that has taken place in the vicinity of the ore deposits.

The determination of the date of the orographic movements that have affected this range is, strictly speaking, subject to the same limitations that obtain for that of the porphyritic eruptions. It is possible, however, to arrive at an estimate of the date which is at least approximately correct by a consideration of the structure of the Great Basin ranges as a whole. Mr. Clarence King,[1] as a result of the Fortieth Parallel investigations, concludes: First, that the Great Basin region suffered a continental or epeirogenic elevation at the close of the Carboniferous, in consequence of which no Mesozoic sediments were deposited in it from the Wasatch Range (longitude 112° W.) westward to Battle Mountain (longitude 117° W.); second, that the Basin ranges were plicated during the post-Jurassic or pre-Cretaceous movement; third, that during post-Cretaceous or Tertiary time they were affected by dynamic movements which produced fracturing and faulting rather than plication.

The probability, therefore, is that the porphyritic intrusions took place in post-Jurassic times, and that these rocks are of relatively ancient date as compared with most of the igneous rocks of the Great Basin region, which were poured out upon the surface during the Tertiary. Of these later effusive rocks none have yet been observed in the Oquirrh Mountains proper, though it is probable that those of the Traverse Mountains, on their eastern flanks, may be found to belong in this category.

ECONOMIC GEOLOGY.

MERCUR DISTRICT.

The only recent publication upon the economic geology of the Camp Floyd or Mercur district, so far as known, is a paper read before the Colorado Scientific Society, at Denver, in the summer of 1894, by Mr. R. C. Hills, who kindly furnished to the present writer an advance copy at the commencement of this investigation.

---

[1] U. S. Geol. Expl. Fortieth Parallel, Vol. 1, pp. 734 et seq. and 744.

This paper, which was based upon a prolonged and most thorough examination of the workings of the Mercur mine, was of great assistance in the present work, and although the conclusions here arrived at differ in some respects from those of Mr. Hills, this investigation has confirmed his observations in the most essential points.[1]

At the time the present investigation was undertaken the opinion generally entertained with regard to the geological relations of the ore deposits in the Mercur district by those who had given most time and labor to the question was briefly as follows:

Two ore-bearing beds, about 100 feet apart, exist near the middle of a great series of limestone strata. The lower of these two beds consists of quartzite or dark, silicified limestone, brecciated and porous, carrying silver with some antimony and copper, but no gold, and is called the Silver ledge. The upper, known as the Gold ledge, is a zone or bed of decomposed, sometimes bleached, sometimes red or yellow, limestone and shale, which carries over considerable areas realgar and cinnabar, together with a low but comparatively uniform percentage of gold, but no silver.

Although it had been remarked that the distance between these two zones or beds varies somewhat from one point to another, it was nevertheless believed that each followed a definite horizon or bed in the limestone series, and the Silver ledge, whose outcrop generally stands out prominently on account of the hardness of the rock, could be traced, it was said, almost continuously from Lion Hill on the north to the southern end of the range. The lithological character of the Gold ledge made it much more difficult to trace, it being marked at the outcrop often by only a slight ocherous appearance in the rock, the gold being under no circumstances visible. Hence there was not the same certainty felt as to its character and extent beyond the deposits already

[1] In justice to Mr. Hills it should be said that his examination was made in the winter, when the snow lay deep on the mountain slopes, rendering observation difficult outside of the mines and hiding the details of much of the geology.

The main points of difference in the conclusions arrived at by the respective observers may be summarized as follows:

1. Mr. Hills considers that Mercur is situated at the crown of a quaquaversal uplift, such as might have been produced by the intrusion below of a body of eruptive rock.

2. Certain cherty zones in the limestone are thought by him to have determined the location of the ore deposits, on the ground that the abundance of chert indicates purification of the limestone by the separation of the silica, and that the mineralizing solutions would have acted more readily upon a pure than upon an impure limestone.

3. The mineralizing solutions are supposed by him to have come from below, and to have ascended through vertical channels now chiefly occupied by veins of heavy spar.

From the present investigations it does not appear that the slight upward bulge in the strata observable in the Mercur Basin constitutes a quaquaversal, as there is no perceptible pitch of the sedimentary series as a whole to the northward, and such variations from the regular NNW. strike as are found are quite local and are due to local causes.

The presence of chert in the limestone is not believed to have had any effect in determining the location of the ore; many other horizons which contain quite as much chert as that carrying the gold ores show no sign of mineralization.

While the mineralizing currents are believed to have been ascending, and some of the vein materials undoubtedly came up through veins now filled with barite, the filling of these veins is believd to have occurred before the introduction of the gold, and hence the latter had no necessary genetic dependence on the barite.

being mined, and one of the important objects of this investigation was to discover some characteristic by which it could be more readily traced.

After the completion of the preliminary part of this work, which consisted in constructing a topographical map of the basin upon which the geological outlines could be accurately delineated and in making a general and comprehensive examination of the geology of this and immediately adjoining districts as well as of the principal mines, the writer found it necessary to return East. Upon his assistant, Mr. J. E. Spurr, there devolved the entire labor of working out in detail the minutiæ of the geological structure of the ore bodies and their relations to the eruptive rocks, of which only the larger bodies at the northern and southern limits of the basin respectively had thus far been recognized. The results of his field observations, which were made with the utmost zeal and geological acumen, and of the laboratory and microscopical examinations which supplemented them, together with his more theoretical deductions with regard to the origin and mode of formation of the precious-metal deposits of the region, are given in the following pages In justice to their author, and in order that he may receive due credit as well as assume entire responsibility for such of his views as are peculiar to himself, they are given in his own words.

His first important discovery was that certain seams or beds of shale-like material, which in the mines generally form the roof of the ore bodies, and both there and on the surface often have very little in their outward appearance that suggests an igneous origin, are in reality thin, highly altered sheets of a white porphyry, called, from the hill on which its largest outcrop is found, Eagle Hill porphyry. No fewer than three of these very thin sheets, one above the other, were traced by him in the ore-bearing zone. It was often the case that field observations could not determine with certainty whether a given portion of the material was of sedimentary or igneous origin, and then recourse was had to microscopical and chemical examinations. It was found that, while these sheets preserve a general parallelism to the stratification, they are by no means strictly confined throughout their entire extent to one and the same bedding plane, but at times cross from one to another, generally at a low angle.

CONCLUSIONS.

The main conclusions arrived at by Mr. Spurr with regard to the ore deposits may be briefly stated as follows:

There have been two distinct periods of mineralization in this dis trict; during the first what is called the Silver ledge ore was formed, and during the second the minerals of the Gold ledge were deposited. In each period the minerals constituting the ore were deposited mainly along the lower contact of a porphyry sheet, where a somewhat porous or brecciated zone had been formed by the intrusion of the igneous material, which the mineralizing solutions reached through fractures or fissures extending downward from the respective sheets.

The principal vein materials of the Silver ledge are silica, barium, antimony, copper, and silver. They are assumed to have been brought up by ascending hot solutions, the metals in the form of sulphides, the barium as sulphate. They were deposited for the most part in the contact zone below the lowest of the three porphyry sheets, and to a limited extent above this sheet. Throughout the whole zone the limestone is almost entirely replaced by silica. The fissures through which the minerals are supposed to have come up have since been filled with calcite.

The principal vein materials of the Gold ledge are realgar, cinnabar, and pyrite, with gold, which was probably deposited as telluride. With them are associated barite and calcite, presumably of earlier formation, together with gypsum and other secondary minerals. The deposits at this horizon are found mainly at the intersection of certain zones of northeast fractures with the lower contact of the middle of the three porphyry sheets, and reach a thickness of 20 feet or more, thinning out to little or nothing away from the fracture fissures. Some of the principal fissures are still open, and show no evidence of filling or erosion by circulating waters. These fractures cut across the Silver ledge, and as a rule do not extend above the Gold ledge.

These are facts of observation. Reasoning from them and others which are given in detail in his text, Mr. Spurr concludes, with regard to the more remote and hypothetical origin of the vein minerals: First, that the minerals of the Silver ledge were pressed out of the cooling body of porphyry with the included water and brought to their present position in aqueous solution; that the characteristic minerals of the Gold ledge, however, were, at an entirely later period, brought to their present position through the system of northeast fractures by fumarolic vapors proceeding from some unknown body of igneous rock which did not reach the surface.

According to these assumptions and those already made with regard to the age of the igneous rocks, the Silver ledge mineralization must have taken place just before or after the Jurassic movement. On general structural grounds it would seem more probable that it occurred after the movement, but if the water which carried the minerals in solution was exuded from the eruptive magma during its consolidation, as Mr. Spurr thinks, this must necessarily have taken place before the plication, as, had the magma been still partially liquid at this time, it would have been forced into all the small cracks and fissures near by that would have been created during this movement.

The period of the Gold ledge mineralization, since it was separated from that of the Silver ledge by the formation of the northeast fractures, must have been later than Cretaceous or as late as Tertiary. Its possible connection with or dependence upon an unknown body of recent eruptive rock is too remote to justify an attempt to fix the period with more definiteness. The theory that metallic minerals have been brought into ore deposits by fumarolic vapors, which is the one generally entertained by geologists of the French school, is one that the present writer is not inclined to look upon with favor, though he admits the logic of Mr. Spurr's reasoning with regard to the deposits under consideration.

The more practical and tangible conclusions which may be derived from this investigation are, that in searching for gold ore in this district it is necessary, first, to learn to recognize and identifiy the porphyry sheet in the field in its many and varied forms of alteration, and then to follow that, rather than any given bed in the limestone series; second, having traced the Gold ledge porphyry sheet, one should follow the intersection of this sheet with the principal zones of northeast fracturing, and prospect the ground downward along these intersections and in their vicinity.

It may further be remarked that it is probable that the oxidized ores susceptible of ready reduction by the cyanide process will be found to be confined to a zone of rock within a very limited distance from the surface, and that explorations in depth will soon reach sulphide and telluride ores, which may have to be smelted. It is, however, fair to assume that these ore bodies are likely to increase in size and richness with depth, and that sulphide ores may be found which are sufficiently rich to be mined at a profit, in spite of the difficulty of their reduction.

CHAPTER I.

THE MERCUR DISTRICT.

At the present time the actually productive region in the immediate vicinity of Mercur lies within a space a mile square, including the Mercur and the Marion mines and the workings immediately surrounding them. In order to study the geology of these deposits an area of 6 or 7 square miles has been mapped. The town of Mercur and the Mercur deposits are nearly in the center of this area, which embraces almost the whole of the basin in which they lie. Not only the gold-bearing districts but also the silver-bearing portions, which have apparently a much more extended distribution than the gold, are included in this basin. To the north this area runs, with no sharp geological boundary, into the districts of Lion Hill and Ophir, while to the south a series of explorations extends to Sunshine. At Sunshine, a mine lying about 4 miles south of Mercur, there are deposits of gold ore which appear to be essentially like those of Mercur, but on account of its comparatively slight development this district has not been included on the map. The Sunshine and the Mercur ores are mineralogically and genetically so closely related as to form a class by themselves, being, so far as at present known, quite distinct from those of the other districts of the Oquirrh Mountains.

STRUCTURE.

In the Mercur Basin there are exposed, within a distance of 5 or 6 miles, sedimentary beds to a thickness of about 12,000 feet. Their structure is very simple. A single anticline with northwest axis covers the entire district shown on the special map. The axis runs through the corner of the mapped tract, west of the town of Mercur, so that nearly all of the rocks shown on the map belong to the northeastern limb of the fold. The null point in the fold, where the rocks lie horizontal, is seen in a section afforded by Lewiston Canyon. In this canyon, about a mile and a half southwest of Mercur, the rocks change from their usual northeast dip and become horizontal, then pass into gently southwesterly dipping strata. Going southwest, the dip gradually steepens, but within a few miles the rocks pass under the Pleistocene formations of the plain. At this point they dip 15° or 20° W.

Going northeast up the canyon from the axis of the anticline, the dip gradually steepens again, and at the town of Mercur it averages about 20° E. Going further on in the same direction with the dip, and crossing the basin toward the steeper mountain side, the dip increases rapidly and somewhat regularly for over a mile; then there is a sudden steepening, so that it passes, within a short distance, from an average of 25° or 30° to about 60°. From the line of this steepening, which is ordinarily well marked all along the line of strike in the district especially examined, the dip is very uniform up to the top of the mountain ridge which separates Mercur Basin from Pole Canyon, averaging about 60°.

Besides this anticline, there are no large disturbances worthy of note. There are some very small irregularities, such as must occur everywhere, and some of these will be noticed further on; but on the whole the structure is as simple an anticline as is generally found. The relative depression of the Mercur Basin, as compared with the higher hills which stand to the north and to the south, along the line of strike, causes the outcrop of the strata, in passing through the basin, to deviate from a straight line in the form of a distinct bulge to the northeast. This appearance is not indicative of any great irregularity in the strata, but is due simply to the recession of the rocks along the dip with the greater erosion. The longitudinal section (E-E, Pl. XXVII) shows that there is actually very little irregularity along the main axis of the fold.

LOWER BLUE LIMESTONE.

The lowest horizon in the district covered by the Mercur map is seen in Lewiston Canyon, under the arch of the anticlinal fold. This is a dark-blue, at times semicrystalline limestone, carrying Lower Carboniferous fossils. It forms a type which is ordinarily distinct from the other limestones of the district by reason of its somewhat darker color, as well as of the granular appearance which it derives from the coarser grain and the typically semicrystalline condition. It is only in Lewiston Canyon that this lowest horizon is exposed within the district shown on the map. Going down the canyon from Mercur, it is met at about three-quarters of a mile from the town, rising up in the bed of the canyon with gentle northeasterly dip. It continues to form the bed of the canyon till very near the point where the canyon opens out upon the plain. At this point the slight southwestern dip has brought it down again, and it disappears below the overlying beds. In the middle of the exposure, directly in the anticlinal arch, a thickness of about 200 feet of this limestone is shown in the walls of the canyon. The bottom, however, is not seen, and so no statement in regard to the total thickness of the horizon can be made. A typical locality of this rock is at the mouth of Quartzite Gulch; this is also one of the best localities for fossils. Specimens collected at this point have been found by Mr. C. H. Schuchert to be of Lower Carboniferous age.

LOWER INTERCALATED SERIES.

Directly above the lower limestone comes a series of alternating thin beds of limestone and calcareous sandstone, with rocks representing various stages between the mainly siliceous and the purely calcareous sediments. This series is about 600 feet thick. The thickest bed of sandstone, which has a thickness of about 100 feet, is at the bottom of the series. From this bed to the top of the series there are frequent alternations of siliceous and calcareous sediments, so closely following one another and presenting such numerous transitions from the one to the other as to show that the entire series was deposited at a comparatively uniform depth, just on the border between detrital deposits and those of organic origin. Nearly all the sandstones are more or less calcareous, and the limestones are usually siliceous.

The contact between the limestone and sandstone beds is, however, usually distinct, showing a decided, if only temporary, change in the conditions of deposition. This distinct contact does not necessarily imply any great change of depth, of currents, of supply of material, or of other conditions. The series was deposited, as before stated, at the critical point of sedimentation—the boundary line between the arenaceous detrital deposits and those calcareous sediments which derive only a small part of their material directly from the degradation of the land. From its nature, and from the complexity of the minor conditions which influence it, this boundary is in no case stable, but must continually swing to and fro irregularly, even when the sea-bottom maintains the same distance from the surface. The closely alternating beds of this series can not, therefore, be taken as necessarily indicating repeated minor oscillations of the sea-bottom during their deposition.

This is illustrated by the fact that the individual smaller beds are not permanent, even over small horizontal distances. Two parallel detailed sections were made up the sides of Lewiston Canyon, where the steep, bare walls are particularly favorable to accurate observation. These sections are about three-quarters of a mile apart, and since the beds lying between them are very nearly in a horizontal position, the distance between the sections is about the same as at the time of deposition. Yet in the more southwesterly section the thickness of this intercalated series seems markedly greater than in the northeastern one. The beds of sandstone are rather thicker, more numerous, and separated by thicker beds of limestone. In the northeasterly section fourteen distinct beds of sandstone were counted; in the southwesterly one, nineteen. From this it will be seen that there is no possibility of finding a perfect agreement between these two localities, and that in the intervening distance some of the sandstone beds of the one section must thin out and be replaced by the limestone which occurs in the other section. This inference is corroborated by actual observation in the field. In the canyon there are places between these two sections where beds of sandstone thin out and are replaced by limestone; and this is so frequent that it is a question whether the exact equivalent of any of the thinner beds of the one section can be found in the other. Yet in a general way the equivalence of the conditions in the two localities may be inferred from the relation of the beds. At the bottom of the northeast section, and near the bottom of the other, is the thickest bed of sandstone in the series, measuring about 100 feet in the one and 120 feet in the other. This bed may easily be traced along the wall of the canyon for the whole distance of the outcrop of the series.

In color the sandstone is generally grayish-green, sometimes reddish. It has a distinctly granular texture and conchoidal fracture, and the detrital grains of quartz are usually visible to the naked eye. In the hand specimen it has all of the usual characteristics of quartzite, except that the application of acid produces a slight effervescence, indicating the presence of lime carbonate. Under the microscope the rock is found to be rather uniform, consisting of rounded grains of quartz in a cement of cryptocrystalline calcite. Ordinarily the sand grains do not touch, but are quite isolated; and the character of the cement, which is exactly like that of the pure limestones, shows that calcite and quartz were deposited simultaneously, and that there has been no considerable alteration since the deposition. In rare cases, where the sandstones have been affected by the silicification attendant upon the mineralization, the rounded grains have become faceted, and then appear as quartz crystals, interlocking or embedded in the fine-grained limestone.

The limestone varies greatly in nature, as might be expected from the varying conditions of deposition. The dark-blue, semicrystalline rock, which has been described as occupying a position inferior to the Intercalated series, has not been seen at a higher horizon. The most frequent type in the Lower Intercalated series is dark gray-blue to slate-gray in color; usually fine-grained and compact in texture. This variety is not crystalline, and generally breaks with a smooth, conchoidal fracture. The rock is the typical limestone of the district, being essentially the same as that which overlies the Lower Intercalated series. It contains frequent concentric, lenticular, or irregular chert concretions, which are conspicuous on weathering, so that the rock very often takes on a rough appearance. The color of the weathered rock varies from light-brown to light-gray or nearly white, depending upon the varying but always small content of iron, while the lower semicrystalline limestone, on account of its great purity, typically retains its dark-blue color on weathering.

A very fine-grained limestone, breaking with a smooth, conchoidal fracture, forms a peculiar type which appears to be confined to this series, since it has not been met with in its typical form anywhere else in the district. It is homogeneous and apparently very pure, being translucent, and has a beautiful, uniform, dove-gray color, both in the fresh state and on weathering. It has all the characters of lithographic stone, but specimens uniform enough to be of commercial value were not noted. This limestone forms a number of thin beds, never exceeding 15 or 20 feet in thickness. It is usually found separating two beds of sandstone.

A single bed in the Lower Intercalated series consists of a snow-white, completely and coarsely crystalline limestone. The bed examined was between 1 and 2 feet in thickness, and was found only in one of the Lewiston Canyon sections. Mineralogically this rock seems to be like a very pure marble, but the crystalline structure in this case can not be due to any pressure or contact-metamorphism subsequent to deposition, for the bed lies between two beds of the translucent, dove-gray limestone just described, and a large fragment of a coral in a comparatively unaltered condition was found in it. This peculiar limestone is also found in one or two very thin beds in the Upper Intercalated series, a similar but vastly thicker series, which forms the uppermost of the rocks of the Mercur Basin. In the pure limestones, however, it has not been met with. It is evident, therefore, that both this and the fine-grained, dove-gray rock owe their origin to peculiar conditions of sedimentation, and from their association with the Intercalated series it is probable that these conditions were simply a peculiar modification of those which obtained for the deposition of the entire series, and were contrasted with those which governed the deposition of the thicker and more ordinary limestones. It is quite possible that both of these peculiar limestones may be due to direct chemical precipitation.

GREAT BLUE LIMESTONE.

Next above the Lower Intercalated series comes the formation which occupies the most of the Mercur Basin. This is a comparatively uniform, massive limestone, of a dark gray-blue color, nearly like that of the Lower limestone. It breaks with a rough, conchoidal fracture; on weathering it becomes pulverulent, greenish or pinkish, or nearly white. From its color one might suppose that it is impure, but an analysis of a typical specimen shows that in reality it is very pure, containing only a small amount of insoluble matter. It is an entirely calcareous limestone, being quite free from magnesia; the color is due to the presence of a small amount of organic material. Usually the outcrop is very fresh, the changed material being carried away as fast as produced, but in many places the alteration products have accumulated, so that the rock is more or less altered to a depth of many feet. A notable instance is seen in the cut for the railroad, just southeast of the Surprise shaft, where the rock has been altered to a light-gray powder for a depth of 20 feet or more, apparently by surface agencies alone.

The upper limit of this rock, which may be called the Great Blue limestone, is not distinct, for it passes gradually into the series next

MERCUR BASIN, LOOKING NORTH.
Marion Hill in left foreground

higher up. Its thickness, therefore, may be variously estimated, according as the upper boundary is defined; the maximum, however, is about 5,000 feet.

SHALE BEDS.

There are certain variations in the nature of the generally uniform sediments which have enough character and persistence to be noticed. Most marked among these geologically, and most important economically, are the belts of black carbonaceous and calcareous shale. These are two in number, one situated near the bottom and the other near the top of the Great Blue limestone. The upper one is the larger and the more persistent in regard to its characters. It lies about 1,000 feet from the top of the Great Blue limestone, if the latter is considered in its maximum thickness, as estimated above; but if it is considered in its minimum thickness, then the shale itself may be held to indicate its upward termination. The shale lies in a strike valley which evidently owes its existence to the more ready erosion of the shale beds, as compared with those of the harder limestones. The thickness of the belt is somewhat more than 100 feet. These shales can not be considered as typical detrital sediments; they are simply phases of the limestone. In places, especially where they have been acted on by running water, they are soft and have no great cohesion; in other places on the same horizon the rock is so hard and contains so much lime that it deserves rather the name of a shaly limestone, if considered without reference to the other localities. Specimens from this shale belt nearly always effervesce with acid. The carbonaceous matter is varying in amount, but never very great. In the Jones-Bonanza shaft, which cuts the shale at a point southeast of Tremont Hill, near the divide between Mercur Basin and Fairfield Canyon, parts of the shale contain coal, scattered thickly throughout it in the form of small seams and layers and as brilliant particles. The lustrous appearance thus given makes the rock seem at first sight to be a useful coal; but it is found that nearly every part will effervesce with acid, and if a piece be burnt the incombustible residue, consisting chiefly of lime, is found to form the larger part of the rock.

The lower shale belt lies about 2,500 feet below the upper one, and about 1,000 feet above the bottom of the Great Blue limestone. Its characters are essentially the same as the upper, but are less emphasized; for, as it is not so thick, its relation to the pure limestone on both sides is closer. This shale belt averages about 25 feet in thickness, but it is variable and often becomes shaly limestone, so that it is not always possible to identify it exactly. These two shale belts carry springs which furnish the entire water supply of the Mercur district.

Just above the larger shale belt are usually thin-bedded, somewhat shaly limestones, which are transitional between the shale and the massive blue limestone. These rocks are distinguished by the thin plates into which they split on weathering, and by the brighter reddish and greenish color of the slightly weathered specimens. There is no sharp boundary between the shaly limestones and the rocks above and below.

UPPER INTERCALATED SERIES.

Above the upper shale belt the rocks begin to contain arenaceous layers, separated by very thick beds of pure limestone. At a distance of about 1,000 feet above the top of the shale these sandstone beds become so common as to mark the lower limit of a new lithological series, the Upper Intercalated series. This reproduces on a larger scale the characters of the Lower Intercalated series. The rock types are nearly the same, but the individual beds are thicker and farther apart. From the bottom of the series to the top of the ridge there are probably about a dozen beds of sandstone, each of which has a thickness of 100 feet or more; yet in places the sediments seem to alternate even more closely than in the lower series. Many of the beds present for considerable distances a complete intermediate stage between sandstone and limestone, and in places layers of mainly calcareous sediments alternate very uniformly with layers which are mainly arenaceous, each layer being only a few inches thick, and the alternation being many times repeated. The thickness of this Upper Intercalated series, as estimated from its base to the summit of the ridge which divides Mercur Basin from Pole Canyon, is 5,000 or 6,000 feet. This, however, is not the top of the series, for the rocks preserve their northeasterly dip for a considerable distance down the other side of the mountain into Pole Canyon before beginning to rise again on the other side of the syncline. The total thickness, therefore, must be upward of 6,000 feet, and may be as much as 10,000 feet.

This series occupies the northeast corner of the tract shown on the detailed map, where a thickness of over 4,000 feet of the strata appears.

RÉSUMÉ.

It will thus be seen that the structure of the rocks of the Mercur Basin is simply that of one limb of an anticlinal fold, the beginning of the other limb being in the southwest corner, as seen near the mouth of Lewiston Canyon. Lithologically this conformable series may be divided into (1) the Lower Blue limestone, which occupies the bottom of the canyon, and of which there are exposed, under the arch of the fold, about 200 feet; (2) the Lower Intercalated series, consisting of interbedded limestones and calcareous sandstones, having a thickness of about 600 feet; (3) above this a very thick blue limestone, which has been designated the Great Blue limestone, and which has a thickness of about 5,000 feet. This limestone holds the beds of shale which furnish the water supply for the district, and is also noteworthy for containing in its lower portion the ore horizons. Above the Great Blue limestone comes (4) the Upper Intercalated series, consisting of interbedded limestones and sandstones, like the lower series, but on a larger scale. Measured to the top of the ridge, which is the margin of the basin, this series shows a thickness of 5,000 to 6,000 feet. There is thus exposed in that part of the Oquirrh Mountains which we have called the Mercur Basin a total thickness of nearly 12,000 feet of strata.

AGE OF THE STRATA.

Fossils were collected from the beds in the Mercur Basin at various points, so as to represent as well as possible the entire series from the Lower Blue limestone to the Upper Intercalated series. These were submitted to Mr. Charles Schuchert, of the United States Geological Survey, who found them all to be of Carboniferous age. According to his report, the Lower Blue limestone and the Lower Intercalated series are in the Lower Carboniferous, while the Upper Intercalated series is probably in the Coal Measures. The boundary between these two divisions can not be closely defined. It may be in the middle or the upper part of the Great Blue limestone, or, more probably, at the top of it. The fossils form a gradually changing series, which begins somewhere above the base of the Lower Carboniferous and seems to terminate in the Upper Carboniferous.[1]

ERUPTIVE ROCKS.

In the Mercur district there are two distinct varieties of closely related eruptive rocks, which form sheets or small dikes in the Great Blue limestone. Both these rocks belong to the class of quartz-porphyries, although they are very dissimilar in appearance.

EAGLE HILL PORPHYRY.

One of these varieties is found in greatest thickness and freshest condition in the vicinity of Eagle Hill, on the divide which separates the Mercur Basin from Sunshine and the southern end of the range. This rock in its freshest condition is nearly pure white, with a grayish, brownish, or sometimes pinkish tinge; it is compact and fine grained, and breaks with a conchoidal fracture and a rough texture. Small phenocrysts of quartz, feldspar, and biotite may often be observed, though they are never conspicuous; rarely the thin plates of biotite become nearly a quarter of an inch across.

A specimen of fresh rock shows under the microscope a finely microcrystalline ground-mass, in places made up of very small spherulites, which occasionally grade into a micropegmatitic intergrowth of quartz and feldspar. Lath-shaped microlites of feldspar are very common, but the main part of the ground-mass is not coarse enough to render the component minerals distinguishable. Phenocrysts are rare, but are fresh when found. They consist, so far as observed, of quartz, biotite,

[1] Of a series of fossil bryozoans and brachiopods from the lower shale belt, recently received, Mr. Schuchert says: "They are of the Osage age (Burlington-Keokuk), of the Mississippian series."—S. F. E.

and orthoclase feldspar. The quartz is in crystals or irregular grains, which show corrosion by the magma previous to the consolidation of the rock. The feldspar has crystal outlines, often rounded by corrosion, and shows no decomposition. The biotite is dark colored and strongly pleochroic; along its cleavage cracks some of the iron has separated out as oxide.

Except where the beds are thickest, the porphyry is usually considerably decomposed, and the thinner the sheet the more, as a rule, has it suffered from contact with atmospheric or other disintegrating agencies. On weathering, the rock loses cohesion and becomes a compact, very fine-grained, chalky mass, so soft as to be easily impressed with the finger nail, or finally a loose powder. The weathered rocks are usually of a cream-yellow color, but they are often stained in a variety of shades—red, yellow, greenish-gray, or nearly black.

The Eagle Hill porphyry seems to be split up chiefly into two principal sheets, which are well exposed on the sides of Eagle Hill. Both are in a general way parallel to the bedding of the limestone, so that they are true sheets; in places, however, the boundary cuts across the bedding at a considerable angle, which sometimes is as much as 90°. In such cases, and in places where only a small part of the contact was observed, it has been supposed that the porphyry is in the form of dikes. Observation of the contacts at special places is very confusing and unsatisfactory in settling this question, but when a continuous contact is mapped and plotted over a considerable distance the true relation of the limestone to the porphyry is very clearly seen.

Since the hills around Mercur are not covered by drift or alluvium, it is comparatively easy to trace continuously the line of contact of the eruptive with the sedimentary rocks. If, as is often the case, the actual boundary can not be seen, it can generally be identified by fragments which lie on the surface, and which are found usually to correspond pretty closely with the solid rock below. In the weathered rock the limestone chips are of the typical dark-blue color, while those of porphyry are cream-yellow, sometimes brown or green; and on a bare hillside the line separating the two can be rapidly traced. If the hill is steep, however, the formation of a talus may hide the contact for a space.

In the Mercur Basin map the uppermost of the two principal sheets is shown east of Eagle Hill on the ridge south of Mercur. The top of the knob next east from Eagle Hill is of limestone, and the porphyry forms a broad belt on its sides. This sheet is probably between 250 and 300 feet thick, but it dies out rapidly, and to the northwest the outcrop does not descend from the hill, but is replaced by limestone. It is not represented, therefore, in any but the extreme southern part of the map, and does not pass through the basin.

The second sheet, which is estimated to be stratigraphically about 700 feet below the first, is found in its greatest thickness and with its rocks

MERCUR BASIN, LOOKING SOUTH.
Mercur Hill in right foreground.

in the freshest condition on the spur between Eagle Hill and Sunrise Hill. The greatest thickness exposed here is probably upward of 300 feet, but it seems to thin with great rapidity to the north and east, and to split into several small sheets. Owing to the northeast dip, these thin sheets are well exposed only in the places of deepest erosion,—in this case in the lowest part of the Mercur Basin, at the head of Lewiston Canyon. Here, owing to their small thickness, they are much decomposed; they are also intimately connected with the ore deposition. There are here three small sheets, averaging about 10 or 15 feet in thickness. On the other side of the basin they seem to unite again, and the porphyry becomes temporarily thicker than in the basin. Yet it is probably nowhere more than 100 feet thick, and usually it is much less. The same general sheet of porphyry has been traced to the northern side of Lion Hill, at a point overlooking Ophir Canyon.

On the southern side of Eagle Hill the upper sheet occupies a considerable area (see map, Pl. XXV, p. 360); the lower sheet seems to be split up into two thin sheets, one of which runs around and joins the upper body, while the other persists in the bottom of Sunshine Gulch, past the Glencoe and the Sunshine mines, till it disappears in the foothills south of Sunshine. Nearly all these outcrops are on the northeast limb of the anticline, where the rocks dip to the northeast.

The arching of the fold causes the outcrop to describe a curve on the southeast side of Lewiston Canyon. Here the porphyry can be traced rising up above the top of the canyon wall, till with the new dip to the southwest it comes down to the bottom of the canyon again at its very mouth. On the other side of the canyon there is a part of the corresponding curve, but it does not appear to be completed, so as to join itself with the first. This may be due to a local disappearance of the sheet.

As before stated, the porphyry has its greatest development around Eagle Hill, and it seems probable that somewhere in this vicinity exists the channel through which it came up from below. The lower sheet is thickest on a line running directly from Eagle Hill to Lion Hill, and appears to thin gradually from the former toward the latter, though the erosion of the deeper valleys has removed it from much of the intermediate region. Northeastward from this line it thins rapidly, and to the northwestward it thickens.

BIRD'S-EYE PORPHYRY.

The other variety of porphyry, called by miners and explorers Bird's-eye porphyry, is exposed on the area of the Mercur Basin map only in the northwest corner. It forms part of two conspicuous eminences, which have been called Porphyry Hill and Porphyry Knob. This rock does not in any way resemble the porphyry just described. In its freshest condition its general color is gray. The porphyritic crystals are well developed, and make up a large part of the bulk of the rock. They consist of light-gray feldspars of rather uniform size, the larger varying from an eighth to a quarter of an inch in diameter; also regularly disseminated biotite in black hexagonal prisms about an eighth of an inch in diameter, and occasional quartz crystals. These, with many smaller phenocrysts, are set in a greenish-gray ground-mass. On decomposition, the ground-mass assumes a deep olive-green color, which becomes brownish in places; the feldspars become whiter, so that they stand out more sharply from the rest of the rock, and the mica assumes a greenish-bronze color. The process of alteration of this rock is as different from that of the Eagle Hill porphyry as are the two rocks in appearance. In the beginning of the process the Eagle Hill variety breaks up into small, sharp fragments, which become dislodged and lie in great numbers on the surface above the solid rock. As disintegration proceeds the rock is finally reduced to the pulverulent state. In the Bird's eye porphyry, however, this is not the case. The alteration proceeds gradually throughout the rock, as it does in the disintegration of granites. The rock does not split or shell, but remains firm till the process is far advanced; hence, by the time it loses its cohesiveness it is so much decomposed as to be ready to form soil. When the rock crumbles the minerals which make up the porphyritic crystals can still ordinarily be distinguished.

On the edge of the Mercur Basin the Bird's-eye porphyry consists of a single sheet, conformable with the stratification and with the sheets of Eagle Hill porphyry. The horizon of the two porphyries is in a general way about the same, although near Porphyry Hill the sheet of the Eagle Hill variety is several hundred feet lower down than the Bird's-eye porphyry. The latter occupies the summit of Porphyry Knob, where it has a columnar structure, which is developed by weathering. Between Porphyry Knob and Porphyry Hill, erosion has worn down through the sheet and revealed the limestone beneath. The southwest slope of Porphyry Hill stands at right angles to the dip of the strata, and the full thickness of the porphyry sheet is shown in section, the summit of the hill being formed of limestone strata. The porphyry outcrop, followed southeast, diminishes very gradually in thickness for some distance, and then terminates so abruptly as to suggest a fault. No other evidence of a fault, however, can be found, and it is certain that no movement of great importance has occurred; moreover, no outcrop of porphyry representing the other side of a fault can be found. Northwestward the porphyry can be easily traced. It runs to the east of Lion Hill and is exposed high up on the northern wall of Ophir Canyon.

The Bird's-eye porphyry in the Mercur district, therefore, is only the edge of the main mass. It seems to have its greatest development considerably northwest of that of the Eagle Hill porphyry, although it appears at about the same horizon and on the same general topographical and stratigraphical line. It is probable, therefore, that they are genetically connected,—that they represent the same general magma which ascended along the line of weakness induced by the mountain building, and crystallized at different times and under varying conditions.

No evidence of value with regard to the relative age of the two varieties of porphyry has been found. In a single place—on Lion Hill—a contact between the two was found, by the side of the road which leads to the mines, but it was of such a character and the rocks were so thoroughly decomposed that no evidence could be derived from it.

PRECIOUS METALS; GENERAL DISTRIBUTION.

A large part of the rocks in the Mercur Basin contain traces of gold, showing a very slight but widespread mineralization. Of two samples of hard, unaltered limestone from the Great Blue limestone, taken at places not in the immediate proximity of ore deposits, one showed a trace of gold, the other none. Two assays of the black shale in the upper belt contained no trace of gold or silver; one assay from the lower black shale belt showed a trace of gold. Nine assays[1] were made of altered limestone in places where the change seems to have been the effect of atmospheric agencies, and not to have been greatly influenced by any important mineralizing action. This altered rock was mostly of the pulverulent, bleached variety, such as is common in surface exposures. It seems probable, therefore, that any precious metals detected in it are only those which were present in the hard limestone, slightly concentrated, perhaps, by the weathering agents. Seven of the nine samples showed very small quantities of gold, the largest amount found being 0.025 ounce in a ton; the other two showed no trace. In none of them was any silver found. Four assays were made of comparatively fresh Eagle Hill porphyry. Two assays showed 0.01 ounce of gold per ton, one showed a trace of gold, and the fourth was entirely barren. Of two assays of the Bird's-eye porphyry, one showed 0.01 ounce of gold to the ton; the other showed a trace of gold. Three assays were made of the calcite veins, which are frequent in the limestone. These veins are of pure white, crystalline calcite, without admixture of other minerals; occasionally, however, they have been stained brown or yellow, probably by a slight admixture of iron. They do not appear to be in any immediate way connected with the chief mineralization. All three of these veins showed small quantities of gold, the largest amount being 0.025 ounce to the ton.

This shows that there is a slight mineralization which is pretty generally distributed throughout the rocks of the basin. On the other hand, in certain localities the mineralization has been so great as to furnish ores of gold and silver which have been profitably worked.

[1] Most of these assays were made for the Survey by Mr. R. H. Officer, of Salt Lake City, Utah, and in an especially careful manner. It is believed that the sources of error in ordinary assaying have been avoided, and that the results are accurate.

These localities, so far as yet shown, appear to be in all cases at the contact of the porphyry sheets with the inclosing limestone. This contact, however, is not always mineralized so much as to form ores—indeed, this condition is the exception. Twelve assays were made of specimens taken at the contact of porphyry and limestone, in places which contained no ore, and where there was no evidence of mineralization or other excessive metamorphism. In some of the samples the rock was quite hard, the limestone showing some silicification and the porphyry also being indurated; in others there had been a disintegration instead of a hardening, and both porphyry and lime were crumbling or reduced to a powder. The results of the assays can not be said to show more gold than is present in many of the other barren rocks of the district. Nine samples showed very small quantities of gold, the largest amount reported being 0.025 ounce to the ton, while three were entirely barren. All of them were examined for silver, but none was found in any case.

In certain localities, however, the contact becomes much richer and forms ore deposits. These deposits are found to be separable into two distinct groups, which are in nearly every characteristic strongly contrasted with each other and must be treated quite independently. In the first group the lime has become hardened at the contact of the porphyry and almost entirely silicified, so that it goes among the miners by the name of "black quartz;" and in this siliceous rock are found films and seams of chloride of silver, with sometimes argentiferous stibnite, sometimes thin films of the copper carbonates, and usually a large amount of barite. In the second group both lime and porphyry have been decomposed and are changed into a soft rock called "shale" by the miners. This is nearly black in the unoxidized condition, but yields very readily to surface influences, and becomes light-yellow, sometimes reddish and brownish. The first group contains only very small quantities of gold along with the silver, while the second contains practically no silver but enough gold to make the ores valuable. This ore is remarkable for the large quantity of arsenic which it contains, and also for the mercury sulphide which is peculiar to it.

The deposits belonging to these two principal groups are generally quite distinct one from another. To the siliceous outcrop characteristic of the first has been popularly given the name of the "Silver ledge," while the rock which contains the gold ores is called the "Gold ledge."

CHAPTER II.

THE SILVER LEDGE.

What is commonly known as the Silver ledge is a zone of highly silicified rock at the contact of the lowest of the three minor sheets of Eagle Hill porphyry which split off from the lower main sheet. The outcrop of this zone is prominent throughout a large part of the basin.

This zone or metamorphic border is sometimes very thick as compared with the size of the sheet of porphyry with which it is associated, while at other places it completely disappears; yet it is a pretty constant accompaniment of the lowest sheet of porphyry, and is never long absent from the contact. Its greater development in places is doubtless to be referred to local causes; but no law governing its general distribution can be found, other than that it characterizes the contact of porphyry and limestone. This phenomenon is confined to the Eagle Hill porphyry. Only the slightest trace of any such alteration was found in connection with the Bird's-eye porphyry.

DESCRIPTIVE GEOLOGY.

The Silver ledge is developed chiefly at the contact of the lower of the two principal sheets of Eagle Hill porphyry, and occurs only sparingly at higher horizons. On the northeast side of Sunrise Hill, overlooking Mercur Gulch, it appears in considerable thickness. The steep cliff into which it has been fashioned by erosion rises for a height of 60 feet or more, and is conspicuous from a distance. This outcrop is continuous for nearly half a mile, but disappears gradually on both sides, and the rest of the contact of porphyry and limestone on this hill does not show it.

MERCUR HILL.

Following the strike, one next finds the Silver ledge well developed on the side of Mercur Hill, just above the bed of Mercur Gulch. It is not so thick as before, averaging about 10 or 15 feet. This is a good place to observe the association of the Silver ledge with the porphyry and the dependence of the one on the other. The Silver ledge is much broken up and contains a good deal of barite. On the under side it changes gradually to hard, unaltered, blue limestone. The line of contact of the Silver ledge with the limestone is neither distinct nor regular, shifting up and down in a way which shows that it can not have been produced by sedimentation, but only by subsequent metamorphism. The rock of the Silver ledge is here much brecciated. The angular or somewhat rounded fragments of cherty, completely silicified limestone are inclosed in a cement which is chiefly of white crystalline calcite, often with barite. Some of the fragments are also of altered porphyry.

The contact of the Silver ledge with the porphyry is quite distinct, and the greater erosion of the porphyry has marked the contact by a shelf 15 or 20 feet wide. The porphyry is considerably decomposed, contrary to its ordinary condition in the Silver ledge, where it has been early indurated, apparently at the same time as the silicification of the limestone, and therefore withstands later altering agents. It is, however, often quite firm. It is of a light-gray color, with no phenocrysts or crystalline structure visible to the naked eye except very small flakes of muscovite. In parts it is stained brown or yellow, and is often quite soft and crumbling. In the limestone below the Silver ledge there are numerous narrow, vertical calcite veins, running N. 18° E. In the broken and altered rock above, these do not appear, and there are no veins in the porphyry. This shows that, in this case at least, the formation of the fissures and cracks since filled with calcite was not later than the intrusion of the porphyry. The breccia of the Silver ledge was evidently formed at the time of this intrusion by the friction of the porphyry sheet against the limestone walls, and the filling up of the spaces between the fragments with crystalline calcite must have followed closely, being among the after phenomena of the contact metamorphism. It seems very likely, therefore, that the fissures in the limestone below may have been opened up at the time of the intrusion of the porphyry, and have been filled with calcite at the same time as were the breccias of the Silver ledge. The porphyry here is 15 to 20 feet thick, and above it the contact with the hard, blue, unaltered limestone is again well marked. A noticeable hardening and darkening of the limestone is found at this upper contact for a space of 3 to 4 feet, but it is very much weaker than that of the Silver ledge at the bottom. This locality offers valuable evidence as to the relation of the gold to the silver ores. The silver ores were worked somewhat by open quarrying at the time of the silver production of the camp.

The division of the lowest main sheet of Eagle Hill porphyry into several smaller sheets appears to take place in the little basin which widens out from the bed of Mercur Gulch, just south of Mercur Hill. In this basin lie the Mattie No. 5 and other claims. At the point where the Silver ledge has just been described these several sheets are developed. That one which is associated with the Silver ledge is the lowest and the thickest, although it probably averages not more than 15 or 20 feet. About 100 feet above this is a smaller sheet, which averages about 8 or 10 feet in thickness, but is very often less. This is usually greatly decomposed, and is associated in the closest manner with the ores of the Gold ledge. At about the same distance above the porphyry of the Gold ledge is a third sheet, the smallest of the three, averaging probably 3 or 4 feet in thickness. This sheet does not appear to be greatly mineralized in any way. All three sheets are exposed on Mercur Hill, but the uppermost thins out and disappears in the bottom of the basin; at least, the continuation of it northwestward has not been traced. It is only the lowest which exhibits the Silver ledge alteration, although the Gold ledge porphyry shows decided traces of this action. The silicification and mineralization of the limestone at the contact with the lower sheet is nearly continuous all along the side of Mercur Hill, where openings have been made on it at various points.

MARION HILL.

In the bottom of the basin, near the town, the outcrop is hidden by the accumulation of drift material from the hillsides; on the north side, however, it appears at the base of Marion Hill, very near the Marion Mill, and follows up the southern side of the hill, rising with the dip. The alteration on Marion Hill and in the immediate vicinity has been especially intense. In many places it is difficult to identify the porphyry, and to distinguish it from altered limestone; and in several places the continuity of the porphyry seems to be interrupted, although the Silver ledge is nearly continuous, and the porphyry found at various points sustains the usual relation to the rock of the Silver ledge. Porphyry in a firm but decomposed state outcrops in the road just above the Marion Mill; and a little farther on, where it is softer, a tunnel is driven for a considerable distance in the prophyry. About halfway up the hill are the old Sparrowhawk mines, which were at one time actively worked. The workings are rather extensive, and the limestone is very much altered. It seems probable that parts represent a breccia of limestone with a porphyry cement, both greatly altered. No undoubted porphyry was seen in the workings, and it may well be that at this point and for some little distance up the hill the sheet became very thin, in places reduced to a mere breccia cement, without, however, interfering with the circulation of the waters which produced the alteration and mineralization of the limestone. A short distance southwest of the Sparrowhawk is an outcrop of softened, decomposed porphyry, into which a prospect tunnel has been run. For some distance from this point the outcrop is not strongly developed, but it forms a conspicuous feature at the head of Marion Gulch.

MARION GULCH AND WESTWARD.

In Marion Gulch is situated the old Carrie Steele mine, which was at one time one of the principal silver producers in the district. The Steele workings are directly under the present Marion mine, from which gold ore is being taken. At this point the Silver ledge has a remarkably broad outcrop, as if the sheet had here taken a local dip to the southward and the uppermost part had been eroded off, leaving bare the altered under-contact, whose angle of inclination corresponds very nearly to the slope of the hill. Much of the rock is brecciated and is full of barite. On the west slope of the ridge, next west of Marion Gulch, the difference in altitude between the top and the bottom of the silicified zone is about 150 feet. The alteration, however, is irregular, and there are within this zone isolated patches of little-altered limestone. All along here the most-altered portion of the Silver ledge is essentially a breccia, in which the masses and fragments of limestone often exceed the amount of porphyry, and sometimes shut it out altogether, so that it has somewhat the character of an intermittent sheet. The upper part of the ledge seems generally to be an altered porphyry, altered and hardened at the contact. Above this is the porphyry, which did not feel the effects of the primary metamorphism, but which has been generally softened by later oxidation. It forms a narrow and irregular belt, and is often entirely wanting. Proceeding up the side of the hill, the Silver ledge is found to be continuously and strongly developed. Just before reaching the top of Fort Hill it is interrupted by an interval of unaltered limestone, which seems to mark a break in the continuity of the porphyry sheet. On the southwestern side of Fort Hill, however, it is again well shown, and forms a continuous outcrop. On it were situated the Queen of the West, the Mormon Chief, and various other silver mines, none of which, however, were very productive. In some of the open cuts the altered porphyry can be seen lying above the Silver ledge, in exposures varying from 1 foot to 5 feet in thickness. The altered limestone is very much stained, and is filled with veins of calcite, the most prominent of which are parallel to the contact and the bedding. This altered zone is here very thick, reaching 50 or 75 feet, although only the upper 20 feet or so is of the highly altered rock typical of the ore-bearing localities. From the Mormon Chief group the outcrop is nearly continuous along the side of Monument Gulch, crossing its bed and continuing, with a few breaks, nearly to the summit of the hill at a point overlooking Rush Valley. There are on the northeast side of Monument Gulch several exploration pits in the Silver ledge. A sample taken from one of these pits, very near where the ledge crosses the gulch, assayed 5.61 ounces in silver and 0.005 ounce of gold. Farther up the hill, on the upper contact of the intrusive sheet (the locality just mentioned is on the lower contact), the Silver ledge is somewhat developed, although by no means so well as at the lower contact. The zone of alteration is narrow and the change plainly not so profound. A sample was selected here from a pit almost directly above the locality from which the sample just mentioned was taken, which assayed in silver 0.16 ounce to the ton, with a trace of gold.

SILVER CLOUD SHAFT AND VICINITY.

Where the lower porphyry sheet is exposed on the hills to the north of the Silver Cloud shaft and tunnel the limestone is silicified at several places along the contact, and the slightly irregular relation of the sheet to the stratification here, together with the unequal erosion, has operated so that several silicified bands form parallel ridges, as seen on the map. This structure is usually supposed by the miners to be due to faulting, but the unchanged position of the associated limestones shows that this hypothesis is not correct. The altered rock is well exposed in Silver Cloud Gulch, but the maximum alteration seems to have taken place in the neighborhood of Silver Cloud shaft.

The Silver Cloud shaft is situated in the bed of Silver Cloud Gulch, just above the point where the gulch opens out into the broad flat in which lie the mouth of Silver Cloud tunnel and the Silver Cloud spring. Here the Silver ledge outcrops as a broken, cherty zone containing an abundance of irregular veining, in which barite is especially plentiful. The shaft is about 55 feet deep, and at the bottom a drift runs about N. 50° E. for nearly 200 feet. The whole 55 feet through which the shaft passes is of the Silver ledge material. Most of it is easily recognized as an altered limestone, for the stratification can be readily seen. In places it appears like a somewhat altered and mineralized quartzite.

The drift at the bottom of the shaft follows a strongly fractured zone, which has a trend of N. 50° E. and a general dip of 70° NW. The actual strike of the rocks is about N. 60° E. and the dip is about 27° SE. The fractures are open, without vein filling. They often show slickensided walls, indicating slight faulting. At the end of the main drift the fissures are especially large, which is probably due in large part to the crumbling and partial erosion of some of the sheeted rock adjoining the chief fracture zone. The largest is wide enough at this place to admit a man's body, and several are wide enough to admit an arm. These fractures are like those in the Silver ledge at the Carrie Steele workings, where a large open fissure, wide enough to receive the body of a man, was encountered, and was explored for ore for a considerable distance, without widening. It was found, however, that the fissure had no connection with the location of the ore; and it will be shown later that all these northeast open fissures are probably later in origin than the ores of the Silver ledge. The rock which the fracture planes cut in the Silver Cloud is extremely metamorphosed. It is an altered, cherty, and broken limestone, generally dotted with small blotches of calcite or barite, giving it a porphyritic appearance under ground. Veins of crystalline calcite cut it in every direction and at the end of the main drift form a perfect network. There are often geodes, some of them as much as 2 or 3 feet in their longest diameter, which are lined with magnificent crystals of dog-tooth spar, making by candlelight a very beautiful sight. Barite is quite common, in small bunches scattered through the rock or in larger pockets, veins, or geodes, where it forms tabular crystals, often an inch long, which are generally frosted with calcite. Very thin films of malachite, azurite, and red oxide of copper are frequently found. There is a cross drift about 75 feet from the main shaft which extends about 100 feet to the southeast of the main drift. Like the main drift, this runs through broken and cherty limestone, with several strong fracture planes. For 25 feet from the end of the drift the roof runs along under the grass roots. About 15 feet from the end there is a coarse fault-breccia, very soft and unaltered, which corresponds in trend and hade with the other fractures. Near the end of the main drift another cross drift runs southeast for 30 feet in broken and cherty limestone. There may here be distinguished a set of minor fractures running at right angles to the main set. In the crevices there is a good deal of the soft white mineral known in Leadville by the name of Chinese talc, with some stibnite and thin coatings of hematite.

It is evident that the open fissures were later in formation than the calcite veins and geodes. The walls of the fissures are sometimes bare, but there is generally a thin coating of calcite; they cut abruptly through the large calcite veins and geodes. In some places, too, there appears to have been a very slight faulting, which emphasizes the same point, the vein or geode being raised or lowered a little on one side relatively to the other.

The contact of porphyry and limestone is shown at several places between Silver Cloud Gulch and Porphyry Gulch in open cuts or shallow shafts. There is here a trench showing the contact very clearly. The porphyry, as exposed, cuts the silicified limestone rather irregularly, but still follows the bedding approximately. It is sheeted parallel to the bedding of the limestone. In places it is much decomposed, and being fine-grained and without noticeable phenocrysts, resembles a sedimentary rock, from which, however, it is readily distinguished by the contact phenomena as well as by its total difference in appearance from the rock of the Silver ledge, which is really an altered sedimentary. The contact is very well defined, which may be attributed to the fact that the indurating and silicifying action has not been intense, as compared with that of the Silver ledge on Marion Hill and immediately west. Near Porphyry Gulch, where the outcrop of the porphyry sheet turns a rather abrupt angle, is a shallow pit, 15 or 20 feet deep. The western side of the pit is on the contact of limestone and porphyry, which at this point is nearly vertical; the eastern side is in a talus deposit. The hardened contact has at one time formed a cliff at this point, at the foot of which talus accumulated and grew until level with the top. At the contact there are plentiful breccias developed, and very good specimens of stibnite in radiating clusters are found. An interesting fact shows that the stibnite was deposited later than the formation of the breccias. In several cases a continuous film of stibnite follows a crevice which passes from a fragment in the breccia to the apparently igneous matrix.

Northwestward along the outcrop of the porphyry, the Silver ledge shows at intervals. It is especially well developed on the northwest side of Silverado Canyon, where much exploration for ore has been made, and where the abundance of the altered limestone and the dis-

FACE OF DRIFT IN SILVER CLOUD MINE.
Showing open fissures in Silver ledge.

tance from the porphyry to which the alteration often extends remind one of the similar outcrop running west from Marion Hill.

Following the same sheet southeast, beyond the area of the Mercur Basin map, the Silver ledge is exposed in various places, while between these outcrops, on the same contact, the softer and decomposed rock is actively prospected for gold. Where the lower belt crosses Sunset Gulch there is a good outcrop of silicified limestone and porphyry, with a sharp contact. The porphyry is light-gray or brownish and very firm, with wavy secondary banding, due to incipient decomposition. An average sample of this rock was assayed and showed 0.70 ounce of silver to the ton and 0.015 ounce of gold. From this point the silicified zone may be easily followed, although outcropping only at intervals, past Glencoe down the road nearly to Sunshine. At no point south of the Mercur Basin, however, has there been found sufficient mineralization to make mining profitable, although it has been attempted at the Glencoe mine.

Along the contact of the upper sheet of porphyry there is very little mineralization or other metamorphic phenomena. On the trail between Mercur and Sunshine, at the top of the divide, there is a slight silicification extending for a short distance, but the alteration, although of the same class as that in the lower sheet, has been neither widespread nor profound, and although it has been prospected it appears to carry only very small quantities of silver.

NATURE OF ORES.

QUARTZ.

It may be said, in recapitulation, that the characteristic and ever-present mineral which accompanies the ore is the cherty impure quartz. Among the miners this goes by the name of "black quartz," and is often considered, although without a great deal of reason, to be a favorable sign, not only in the Silver ledge, but also in the gold ores, where it is more sparingly present. Very few ledges of this dark chert can be found which do not contain some silver, but in most of them there is no considerable quantity. Complete silicification was evidently one of the primary stages of the metamorphism, and did not necessitate such violent action as did the introduction of the ores. This is exactly what should be expected, when we consider the abundance of silica as compared with the quantity of the metals in the natural solutions which we have the opportunity to examine. It is somewhat peculiar, however, that the quartz which was introduced so abundantly at this time is almost entirely in this impure, megascopically amorphous condition and that very little of it found an opportunity to crystallize. This fact is significant of the conditions of mineralization. Quartz in crystals large enough to be recognized without the use of the microscope is rare, in both the gold and the silver ores. It occurs in cavities of small size and irregular form, which have evidently been produced by dissolution, and which are entirely inclosed by the surrounding rock. On the walls of these cavities it forms frosty coatings, of which the individual crystals can be well made out only with the aid of a magnifying lens. Along small, irregular, minor cracks it has also often separated out, and it forms coatings of the same nature on the barite, when the latter is crystallized in such a manner as to leave spaces between the individuals.

CALCITE.

Next in order of abundance among the characteristic minerals of the Silver ledge comes calcite. The silicifying solutions which replaced the limestone with silica deposited very little quartz in the numerous vein-like cavities which were developed at the time of the same metamorphic action. The lime, on the other hand, after being entirely expelled from the rock, came in and crystallized plentifully as pure, white calcite in the numerous fissures and cavities which were opened by the silicifying solutions, forming veins, often several inches wide, and lining the walls of large cavities with beautiful crystals of dog-tooth spar. These veins are found nearly everywhere. Sometimes they become so abundant as to form no inconsiderable part of the bulk of the rock; and yet they are somewhat more indicative of considerable mineralization than is the silicified limestone alone. This does not necessarily show, however, any close connection in deposition between the calcite and the ores. More probably it is really the honeycombed condition of the rock which is significant of the intensity of the action accompanying or inducing mineralization, and the calcite, coming later, filled by a much slower process the cracks and irregular cavities formed by the corrosive action of the mineralizing solutions. The calcite veins are not intimately associated with the ore. They are usually quite barren, which is another fact pointing to the same conclusion.

BARITE.

Next in order of abundance comes barite, which is more restricted in its distribution than the other minerals previously described, and also more closely associated with the occurrence of the ores. It is somewhat different in habit from either the calcite or the quartz. It occupies irregular spaces in the rock, scarcely ever forming veins with well-defined walls and constant width and direction. Often portions of the cherty rock of the Silver ledge are included in it, so that there is a resemblance to a breccia; but frequently there is at the contact of barite with chert a zone of transition from one to the other, which suggests that the barite may have replaced the limestone at the time of silicification, and that barite and silica were contemporaneous in introduction. Some of these irregular masses of impure barite are several feet in diameter, and such a body may be seen outcropping on the road leading up the hill from the Marion Mill; but there is much that is disseminated in the rock in small blotches, without conspicuous crystallization. Tabular crystals of barite are often found lining the walls of small cavities, which in most cases they nearly fill. These crystals are irregularly aggregated, leaving spaces between the individuals, and are grayish-white in color. They are usually frosted with very small and perfect crystals of quartz or calcite, which often entirely conceal the barite.

Although the best ore of the Silver ledge does not always accompany the barite, yet in a general way this mineral is a sure index of considerable mineralization. It is especially plentiful in those portions of the ledge from which ore has actually been extracted, such as the Silver Cloud, the Sparrowhawk, the Carrie Steele, and other claims; while in the poorer portions of the ledge it is much less frequent. It has actually been observed, in places, that the barite is the gangue in which are embedded the small portions of the metallic sulphides that doubtless furnish the ore. But although it is the gangue of the ore, it appears that the barite itself does not necessarily contain silver in any large quantity. An assay was made of a specimen from the Silver ledge in Gold Dust Gulch, not far above the Geyser Mill, which was estimated to contain 50 per cent of barite. In some of the specimens from this same place small particles of stibnite were found inclosed in the barite. The assay showed only 0.54 ounce of silver to the ton, with no trace of gold.

STIBNITE.

Antimony is a constant and characteristic accompaniment of the Silver ledge ores, and in its recognized form occurs as stibnite. It is never in large quantities, forming at the best sparingly disseminated bunches of thin, radiating crystals, which rarely exceed an inch in length. It also occurs as small bunches of irregular shape, each bunch being only a small fraction of an inch in diameter, and very commonly in thin films filling crevices in the rock.

Stibnite is associated with silver in the very closest way. It is probable, indeed, that in their primary state the two metals crystallized together. Mr. R. C. Hills, in his paper on this district,[1] states that in one claim "the silver-bearing material is an argentiferous sulphide of antimony." A specimen of the antimony sulphide taken from the contact of porphyry and limestone, at a point near Porphyry Gulch, east of the Silver Cloud shaft, was examined for silver. Only a very small quantity of the mineral was available for analysis, and the results were not conclusive. A faint mirror was obtained, which was probably silver, but which was so small as to leave its presence doubtful. The analysis of silver ore from the Sparrowhawk mine shows a considerable amount of antimony, although no antimony mineral was noticed as megascopically present in the ore. (See p. 394.)

COPPER.

Thin films of copper, chiefly the carbonates malachite and azurite, are found in several places in the Silver ledge, and, like antimony, seem to be very closely associated with the silver. These very small quanti-

[1] Proceedings of the Colorado Scientific Society, August 6, 1894: Ore deposits of Camp Floyd mining district, Tooele County, Utah.

ties of copper show at the same time the connection and yet the difference between the ores of the Mercur district and those of the Ophir district, to the north, and the Tintic district, farther away to the south. In both these districts copper forms a conspicuous part of the ores; in Tintic it has been an important article of production. These copper stains are abundant in the rock at the Silver Cloud shaft. A specimen was selected for assay, consisting of many fragments from various parts of the workings, each bearing a film of copper carbonate. The results showed 25.9 ounces of silver to the ton, and 0.04 ounce of gold, the largest of fourteen assays of various portions of the Silver ledge.

ARSENIC.

The analysis of the Sparrowhawk ore shows a small quantity of arseniates. The arsenic is never, so far as observed, recognizable megascopically in the rocks of the Silver ledge; and in only one section has it been noticed microscopically. In this case a chert which carried megascopically large flakes of stibnite showed under the microscope numerous small grains of scorodite. It may be that some of this arsenic is an original constituent of the ores of the Silver ledge; but where these ores are overlain by the gold ores it is probable that much of the arsenic has leached down from the latter. One of the characteristic features of the Gold ledge in its unaltered form is arsenic in the form of the sulphide, realgar. The ore oxidizes very readily to a considerable distance below the surface; the realgar is converted chiefly into arseniates, among which the arseniate of iron, scorodite, is most abundant. These arseniates are very soluble in the ordinary atmospheric waters, and show evidence of being leached out of the gold ore. It is only natural that some of these solutions should sink to the Silver ledge below and there leave a portion of their burden, taking up new elements with slightly changing conditions. No sulphide of arsenic or other arsenic mineral in recognizable quantities has been found in the Silver ledge.

CHINESE TALC.

A soft, white, clayey mineral, which appears to be identical with the Chinese talc of Leadville, is found quite abundantly filling crevices vein-wise in certain parts of the Silver ledge. A great deal of this was found in a part of the Silver Cloud workings. It is thus described at Leadville by S. F. Emmons:[1]

> The miners' term, Chinese talc, has been retained for a substance which is found with singular persistence along the main ore channel or at the dividing plane between White Porphyry and underlying limestone or vein material, and also at times within the body of the deposit. It is composed of silicate and a varying amount of sulphate of alumina, to which no definite composition can be assigned. It is compact, semi-translucent, generally white, and so soft as to be easily cut with the finger nail. It is very hygroscopic; hardens and becomes opaque on exposure to the air.

[1] Geology and Mining Industry of Leadville, Mon. U. S. Geol. Survey, Vol. XII, Washington, 1886, p. 377.

On page 603 of the same work this mineral is classified among the alteration products of porphyry, and five complete analyses are given. The Mercur mineral has not been analyzed, but it is in all outward characteristics the same as that in Leadville, and, like it, seems to be an alteration product of the porphyry. It is believed not to have been formed at the same time as the barite, stibnite, and silver, but to have had a later and slower formation, keeping pace with the decomposition of the porphyry.

PYRITE.

Pyrite is not recognizable megascopically in the ores of the Silver ledge, and the analysis of the Sparrowhawk ore shows that it is absent. In a single thin section from the Silver ledge in Silver Cloud Gulch, some distance above Silver Cloud shaft, pyrite in small, irregular grains and seams was noted.

GOLD IN THE SILVER LEDGE.

It appears from nearly every assay of the silver ores that they constantly contain very small quantities of gold. Of fourteen assays made of ores from various parts of the Silver ledge, all but one were found to contain some gold. Four of the thirteen gold-bearing specimens showed only traces; the rest contained weighable quantities, although the greatest amount in any one was only 0.04 ounce to the ton. Several other samples contained very nearly as much. From this constant occurrence it follows that, contrary to the common belief at Mercur, gold in small quantities is a very constant accompaniment of the silver ores. It is also evident that this gold is very closely associated with the silver, if indeed it was not deposited at the same time. To account for the occurrence of gold in the silver ores of Marion Hill it has been assumed that the metal had leached down from the gold deposits above, and thus was an impurity of very recent origin. This hypothesis is very plausible when the locality is in the immediate vicinity of the gold ores, but in point of fact the sample which showed the largest amount of gold in the silver ores was taken from the Silver Cloud shaft, at a considerable distance from any known gold mineralization. There are certain places on this horizon where a larger amount of gold has been found, but here the characters of the rock, as well as the contents, indicate a transition between the silver and the gold deposits. They will therefore be described when the relationship of the two is considered.

SILVER.

The silver ores of the Mercur district differ distinctly from the ordinary varieties in being accompanied by very little metallic gangue. Especially are they different from the ordinary silver-lead ores of this and other regions in that they do not contain a trace of lead. The ore consists of very small films of chloride of silver disseminated through the altered and silicified limestone, and in most places it does not appear to be closely associated with any other mineral. It is therefore difficult to judge the value of the ore by inspection, on account of the absence of accompanying baser ores; for there may be enough silver chloride scattered through the rock to make the ore valuable, and yet it could hardly be detected.

Fabulous stories are told of the richness of small pockets of ore which were taken out of the Sparrowhawk and the Carrie Steele in the old days. But opposed to these is the fact that the mines were never for any considerable space of time remunerative, even when silver was at double the present price. To offset the small bunches of rich ore, there are large quantities of rock very poor in the metal. Of the assays made in the course of the survey of the district, the largest return was of a picked sample from the Silver Cloud shaft, which assayed 25.9 ounces to the ton. A general sample from the Mormon Chief mine, on Fort Hill, yielded 19.15 ounces of silver; another general sample from the same place gave only 0.21 ounce. This shows the great variation. The lowest amount of silver found in the typical completely silicified rock was 0.16 ounce to the ton. The mineralization may be characterized, therefore, as very variable in any one place, but remarkably uniform considering the vast amount of the silicified rock which outcrops along the contact and which everywhere shows ponderable quantities of silver.

ANALYSIS OF SILVER LEDGE ORE.

Following is the result of a complete analysis of a sample of the Silver ledge rock, taken from various points in the Sparrowhawk workings on Marion Hill. The analysis is by Dr. W. F. Hillebrand, of the Survey:

Analysis of the Sparrowhawk ore.

	Per cent.
Silicon dioxide (SiO_2)	81.70
Titanium dioxide (TiO_2)	.20
Aluminum sesquioxide (Al_2O_3)	3.24
Iron sesquioxide (Fe_2O_3)	5.41
Iron protoxide (FeO)	.28
Iron disulphide (FeS_2)	None.
Manganese protoxide (MnO)	None.
Calcium oxide (CaO)	.44
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.43
Magnesium oxide (MgO)	.16
Potassium oxide (K_2O)	1.10
Sodium oxide (Na_2O)	.12
Lithium oxide (LiO)	Strong trace.
Water below 110° C	.29
Water above 110° C	2.16
Sulphur trioxide (SO_3)	2.97
Phosphorus pentoxide (P_2O_5)	.05
Antimony pentoxide (Sb_2O_5)	1.02
Arsenic pentoxide (As_2O_5)	.40
Arsenic disulphide (As_2S_2)	None
Molybdenum (Mo)	Strong trace.
Tellurium (Te)	Strong trace.
Total	99.97

GENESIS OF THE SILVER ORES.

It may be said, in recapitulation, that the original form of the silver in the Mercur district seems to have been a sulphide, which crystallized simultaneously with sulphide of antimony and small quantities of copper. It is probable that the copper was also originally in the form of sulphide, although not now found as such. These metals are sparingly distributed in a gangue of barite and of very abundant quartz.

LOCUS OF MINERALIZATION.

The mineralization has taken place at the contact between the porphyry and the limestone, especially the lower contact. Typically the point of greatest mineralization is in the limestone directly on this contact, and from this point it extends into the limestone away from the porphyry, the amount of mineralization decreasing with the increasing distance. The effects of the metamorphism totally disappear at a little distance from the contact, and the limestone below is of an entirely unaltered character. The thickness of the zone of alteration is generally not more than 10 feet; in the most highly mineralized places it becomes 20 to 50 feet, and 100 feet may be safely considered its maximum. So far as observed, nowhere does the mineralized zone deviate in any noteworthy way from this line of contact; nowhere does it extend for any considerable space into the porphyry, and nowhere does it follow any steeply dipping zone, such as would be caused by planes of fracture or by any other structure. Moreover, in the zone which is actually mineralized there are no fractures or other obvious water channels through which the mineralizing agents could have come, except the complicated and nonpersistent minor fractures which are so plentiful in the limestone at the contact with the porphyry. These minor fractures, which become so profuse as to produce breccias, are well developed only at the contact, and they diminish rapidly with increasing distance. Their chief direction is seen in many cases to correspond to the local trend of the contact, and every indication shows that they were formed at the time of the intrusion of the porphyry by the friction of this rock on the rigid sedimentaries.

NATURE OF MINERALIZING AGENTS.

The assembled phenomena indicate that the mineralizing agents were heated waters, which circulated along the contact for a comparatively brief period, during which, however, they appear to have been very active. These waters contained silica, with a good deal of barium, and small quantities of antimony, copper, and silver. The commonest work of these solutions—the removal of the lime and the deposition of the silica by a process of gradual replacement, without destroying many of the original features of the rock—is a phenomenon which has been many times noted as the result of circulating waters, especially of heated waters. The various stages of the alteration here in Mercur have been observed under the microscope. In Leadville the same alteration phenomena are abundantly shown, for there the limestones in the immediate vicinity of the ore deposits are largely altered to chert, and the derivation of one from the other is very clear. Mr. Frank Rutley[1] has described several cases of cherts owing their origin to the gradual replacement of limestone by silica from ordinary surface waters, and is of the opinion that the fine-grained siliceous rocks of Arkansas, known as novaculites, are of this origin. The silicification of sedimentary rocks in the neighborhood of eruptive masses has often been observed as one of the most conspicuous among contact phenomena. Daubrée[2] points out that in the vicinity of eruptive rocks quartz has often accumulated in compact crystalline masses or in a jasperoid condition; and the same observation has been made by other geologists. G. W. Hawes shows that at the contact of the Albany granite with the schists, the latter rocks have become dehydrated and silicified.[3] Changes of a similar nature have been observed in the Hartz, where limestones have been silicified near granite, forming a broad alteration zone following the contact.[4] Geikie speaks of the induration of rocks as one of the most common phenomena of contact metamorphism, and one which results, generally, from the deposition of silica from heated waters.[5] "The most obvious examples of this action," he says, "are those wherein the percentage of silica has been increased by the deposit of a siliceous cement in the interstices of the stone, or by the replacement of some of the mineral substances by silica." It is evident, then, that the silicification of the limestone of the Mercur district at the contact with porphyry is nothing new, but is one of the frequently observed effects of contact metamorphism.

As Daubrée has shown, it is to the action of waters accompanying the eruption of rocks that most of the effects of contact metamorphism are due, and not to the effects of heat alone. Dry heat, indeed, plays an inconspicuous part. Eruptive rocks in the molten condition contain a notable quantity of water which has apparently been derived from the same deep-seated source, and has had the same history from the time of the upward movement of the lava, as have the other constituents. The study of volcanic action makes it appear probable that a large part of this may formerly have been atmospheric water, which has reached the deeper regions by gravity, capillarity, or confinement within sedimentary beds and subsequent deep burial beneath other strata. Having attained the deeper region, this water, under the influence of the high temperature, would become possessed of tremendous expansive force, which must finally find relief in the direction

[1] On the origin of certain novaculites and quartzites; Quar. Jour. Geol. Soc., Aug., 1894.

[2] Géologie expérimentale, Paris, 1879, p. 136.

[3] Am. Jour. Sci. (3), 1881, Vol. XXI, p. 28.

[4] Lossen, Zeitschr. Deut. geol. Gesell., Vol. XXIV, 1872, p. 777.

[5] Text-book of Geology, 1885, p. 558.

of least resistance—that is, in the direction of the surface. It would then ascend by the easiest channels, carrying with it the molten material with which it had become intimately mingled during its sojourn in the depths. But, for the purposes of economic geology, it is perhaps not profitable to go back so far. We may content ourselves with the generally admitted fact that water forms an essential part of lavas, from the moment when the ascent from the subterranean reservoir begins; previous to this it may have been derived from surface sources, or may be a product of chemical reactions in the unknown workshop of the earth's interior. The water which the lavas contain is not emitted till the actual moment of solidification, when by the process of crystallization it is separated out and becomes conspicuous among the now solid components by reason of its persistent fluidity. When the solidification takes place at the surface it forms the clouds of steam which issue from cooling lavas; but where the rock is intrusive, so that the water which is separated is still under sufficient pressure to keep it in the liquid state, there must result intensely heated solutions, capable of a great degree of corrosion. These solutions must act most violently at the contact; they become rapidly cooled on penetrating the adjoining rock, and in the case of small bodies of igneous rock they probably become at a short distance incapable of any great altering power. "The singular property that the molten silicates of lavas possess," says Daubrée,[1] "of retaining for a very long time, and up to the moment of their solidification, considerable quantities of water, clearly demonstrates that the action of heat does not exclude that of water, and seems to show that the latter has, even at high temperatures, a certain affinity for the silicates."

The width of the zone of alteration thus following the contact of an igneous with a sedimentary rock varies constantly with the nature and size of the intruding mass, the nature of the sedimentary rock, and other conditions. Along the same contact, moreover, between the same eruptive and the same sedimentary rock, there are great differences. But it has been remarked that at points where the eruptive rock forms reentrant angles the zone of alteration is greater than at projecting angles.[2]

In the alteration of the limestone near the porphyry in the Mercur district are found very nearly the typical phenomena of such contact metamorphism. There is the unvarying silicification of the limestone, and the approximate continuity of the alteration zone with the contact, together with considerable differences in intensity and amount of alteration at different points. Somewhat the same relation as is noted by Daubrée between the width of the altered zone and the reentrant angles formed by the igneous rock at the contact has been observed at Mercur. As will be seen by inspection of the map (Pl. XXVI), the

[1] Géologie expérimentale, Paris, 1879, p. 152.

[2] Op. cit., p. 134.

greatly altered limestone in the vicinity of the Silver Cloud shaft is situated in such a reentrant angle, and doubtless this is the cause of its great metamorphism, for in such a position the limestone is exposed to the porphyry on two sides, and therefore to a proportionately augmented amount of the metamorphosing solutions.

DURATION OF ACTION OF SOLUTIONS.

Apart from theoretical considerations, the actual phenomena of the Silver ledge indicate brief and intense action. That the waters must have been highly heated and capable of great metamorphosing influence, is shown by the complete replacement of the limestone by silica, and by the great corrosion which the rock has undergone. The whole mass is full of irregular cavities of dissolution, especially where the alteration has been greatest; some of these are of considerable size, occasionally several feet in diameter, while the others are small. Where the change has not been so great, there is still a complete silicification of the limestone, but the dissolution spaces are not so numerous. This may, perhaps, indicate that the formation of the cavities was in general slightly posterior to the silicification, and therefore that the process included the dissolving out of silica. But whether the material which was removed from these spaces was lime or silica, such a riddling of the rocks as is occasionally seen must indicate very active agents of solution. On the other hand, it is shown by the fact that the effects of this change do not reach far from the contact that the action could have gone on for a comparatively brief period only, and therefore that the supply of metamorphosing solutions was soon exhausted.

SOURCE OF BARITE AND OTHER CHARACTERISTIC MINERALS.

The barium, which is found in the Silver ledge in the form of heavy spar, was also probably derived from the cooling eruptive mass. This element is of frequent occurrence in igneous rocks, although rare in sedimentaries. It is often found in the feldspars, and forms an essential constituent in one variety—hyalophane. At Leadville chemical analysis showed barium to be commonly present in the porphyries, while none was found in the sedimentaries.[1] For the metallic constituents, relatively small in amount, the same source may be looked to. The researches of Sandberger and of American geologists have shown that most of the metals found in veins are present in the eruptive rocks, probably as original constituents, especially in the dark-colored silicates, such as biotite, hornblende, and olivine.[2] These metals, therefore, were probably present in the magma. On crystallization a portion of them would be taken up by the forming minerals,

[1] Geology and Mining Industry of Leadville, Mon. U. S. Geol. Survey, Vol. XII, 1886, p. 592.
[2] F. Sandberger, Untersuchungen über Erzgänge, 1882.

and the small amount left, dissolved in the heated waters expelled at the same time, would be carried out and deposited in the inclosing rock, wherever conditions were favorable.

GENERAL ASCENDING MOTION OF SOLUTIONS.

Inspection of the map and consideration of what has already been said will disclose the following significant facts concerning the distribution of the Silver ledge mineralization with reference to the different sheets of Eagle Hill porphyry at various horizons. The upper and larger sheet, if contact metamorphism were dependent on the heat exerted by the molten rock, should show the greatest effects of alteration; actually, however, it shows the least. In only one place on the map is a Silver ledge mineralization of the upper sheet indicated, and in this place it appears from its effects to have been neither intense nor prolonged. The phenomena include little besides the complete silicification which has been mentioned as the most elementary stage of the alteration, and the zone which has undergone this change is only a few feet thick. Nowhere on this contact has the mineralization been sufficient to tempt the working of the rock as ore. It is on the lower of the two chief sheets that the strongly marked mineralization is found. Again, when this lower sheet is undivided the mineralization is characteristically greater on the lower contact than on the upper. When it splits into several thin sheets, as it does in crossing the actually productive mining region, the Silver ledge mineralization is confined chiefly to the lowest of these sheets. On the middle sheet, with which the gold ores are associated, there is evidence of some small amount of mineralizing action, identical and probably contemporaneous with that of the sheet below. This will be mentioned later, in the consideration of the gold ores and their relation to those of silver. The amount of alteration, however, is not at all comparable to that of the typical Silver ledge. Finally, along this lowest thin sheet, the alteration is chiefly on the lower contact, though also developed on the upper contact, and sometimes strongly. These facts may be summed up in the concise statement that the Silver ledge contact-metamorphism follows the contact of the Eagle Hill porphyry with the inclosing rocks, and no other line, and that the metamorphism becomes progressively more profound with the lower horizons.

It is not implied by the application of the theory of contact metamorphism to the explanation of these alterations that the solutions which have altered the rock at any one locality have been derived solely from that portion of the eruptive rock which is immediately adjacent. Considering the probable processes, this is evidently unnatural. The solutions, exuding at every point from the cooling rock, must have found in the limestone immediately adjacent a zone where the passage of solutions was made relatively easy by the opening of fissures and the formation of breccias, this zone being due to the strain exerted on the rigid inclosing rocks by the moving lava at the time of its intrusion. These waters, being, as has already been stated, intensely heated and under great pressure, would tend to move along this broken zone, and, wherever possible, in an upward direction. The porphyry in the Mercur district is in the form of sheets, but somewhere in the vicinity there must be some more direct connection with lower regions; and in the district actually mapped it is found that the sheets often cut across the stratification. At such places as these the waters would rise rapidly, and would traverse a much greater distance from their point of emergence from the cooling lavas than where the broken zone was horizontal. At points where the circulation was retarded, owing to the more nearly horizontal position of the channels, or more probably to the slighter development of the broken zone, the waters would accumulate and the mineralization would be greatest. It is along the minor bodies of porphyry that the mechanical disturbance occasioned by the intrusion must have been least, and here, therefore, the solutions accumulating from the freer passageways at the contact of the larger bodies would produce the greatest mineralization.

This explanation applies satisfactorily to the phenomena described. To the general ascensional tendency of the waters which followed the contact may be attributed the increasing mineralization with greater depths. The lower contact of the lowest sheet would receive not only the waters derived from its immediate locality, but also a possible supply ascending along some feeder lower down, and these solutions would exert a constantly diminishing influence on the successively higher contacts. Moreover, the greatest mineralization does not necessarily attend the largest sheets of porphyry; on the contrary, the most metamorphism, as mapped in the Mercur Basin, is at the contact with the smallest sheets. The chief alteration is that which follows the contact of the lowest thin sheet, after the main lower sheet splits into several. Here the thickness of the porphyry probably does not average more than 20 feet, while the main body, as exposed just south of Sunrise Hill, is several hundred feet thick; but at the contact of this thick sheet the alteration is comparatively small. The application to this case of the theory already stated would be that the solutions proceeding from the larger mass of the main sheet were retarded in their progress by the more difficult passage which the more slightly fractured zone along the smaller sheet offered, and so here produced the most marked effects.

While the theory which has here been adopted for the origin of the mineralizing waters appears the most satisfactory, it is not meant to disregard the possibility that they may have been derived from other and commoner sources. Surface waters, sinking into the earth, come in contact with bodies of heated rock, and then rise to the surface again, emerging as hot springs. The extreme importance of this hot-spring action in the formation of ore deposits is generally recognized, and some particular phase of this action may possibly account for the silver ores of Mercur.

EFFECTS OF CONTACT METAMORPHISM ON THE PORPHYRY.

It is a fact which has an important bearing on the theory of the mineralization of the Gold ledge, as subsequently stated, that where the alteration has been greatest along the Silver ledge contact, not only the limestone, but to a less degree the porphyry, has been changed and indurated. This action is especially conspicuous where the alteration of the limestone has been greatest, as on Mercur and Marion hills; also on the boldly outcropping ledge which runs west along the edge of the Fort Hill ridge, and in the vicinity of Silver Cloud shaft. In places like these the actual contact is generally quite obliterated, and the two rocks are confounded so that it is often difficult to decide whether a certain specimen was originally porphyry or limestone. Below this anomalous zone the rock is of the cherty sort which is usual in the Silver ledge. Above, the light-brown color, the lack of any trace of stratification, and the irregular manner in which the rock is distributed show that it was originally porphyry; but it is always hard and siliceous, and has apparently been so indurated that it is not readily susceptible to later changes. Weathering agents have attacked that which was not altered at this time, and decomposed it so that it is reduced to a soft powder or clay, or has so little cohesion as to be easily broken with the fingers, but the indurated porphyry described above has been little affected. Where the lowest thin sheet of porphyry crosses the Mercur Basin, in the vicinity of Mercur and Marion hills, it has been thus indurated for the most of the distance. At intervals portions of the rock are found which have escaped this action and thus prove the original nature of the whole. This phenomenon is believed to have a considerable bearing on the question of the nature and origin of the gold ores, as will be described later.

SUMMARY OF SILVER LEDGE GEOLOGY.

The presence of silver ores is one of many phenomena characterizing a zone of altered limestone which follows somewhat irregularly the contact of Eagle Hill porphyry, especially that of the lowest sheet, and more especially that of the lower surface of the lowest sheet. This zone is marked by the complete silicification of the limestone and by the presence of barite in irregular masses, with small amounts of stibnite and a little copper and silver. The copper is in the form of a carbonate; the silver occurs as chloride, and probably also as sulphide, associated with sulphide of antimony. There is also evidence of a considerable degree of straining and fracture at the time of the introduction of the eruptive rock; breccias are very common and are often on a large scale; many fissures cross the altered rock, but do not persist far into the mass of unaltered limestone, and there are irregular cavities which have evidently been formed by the corrosive action of circulating solutions. The walls of these cavities and of many of the fissures are often thickly covered with calcite, whose large and perfect crystals indicate a slow and quiet period of formation, and which was evidently deposited soon after the main alteration.

It is probable that all of the silver and copper, together with the antimony, was originally deposited as sulphides. The nature of the phenomena of the altered rock, briefly recapitulated above, shows that the mineralizing agents were waters. These mineralizing waters contained in solution chiefly silica, with considerable barium and small amounts of antimony, silver, and copper, which were deposited in the usual form for deposits not immediately connected with the surface—the silica as quartz, the barium as sulphate, and the metals as sulphides.

The completeness of the change in the Silver ledge and the evidence of active corrosion exhibited by the spaces of dissolution show that the action must have been temporarily intense, while the relatively narrow zone occupied by the altered rock and its failure to extend far from the most severely broken zone indicate that the action could not have been prolonged. The absence of large bodies of the metals, which, being relatively rare in solutions, require a considerable duration of chemical activity to accumulate in large bodies, is one of other circumstances which point to the same conclusion. Since the waters were endowed with great dissolving power in a short space of time, they were probably greatly heated. The fact that the mineralization clings so closely to the porphyry indicates that the waters were either derived from the igneous rock or, at least, had a common origin with it; the minerals which the waters deposited are such as would be derived from the porphyry.

These phenomena coincide with those which are most typical of the studied cases of contact metamorphism, and this appears to furnish the best explanation for the origin of the deposits. Briefly, the water which accompanied and was perhaps the motive cause of the eruption was separated from the lava at the moment of cooling and found its way into the adjoining rock. Being still intensely heated, and carrying in solution many of the chief elements of the eruptive mass, it exerted for a comparatively brief period a powerful altering force on the easily soluble limestone, and in the course of this alteration the ores were deposited. The deposition of the crystalline calcite veins may be assumed to have marked the final stage of this action, when the waters were much diminished in quantity, cooled, and deprived of the corrosive agents which they originally held in solution. At this latter period the currents, instead of tending always away from the contact into the limestone, may often have been reversed, and have introduced lime to fill up the cavities.

CHAPTER III.

THE GOLD LEDGE.

The gold-bearing horizon in the vicinity of Mercur and Marion hills lies a short distance above the Silver ledge. On Mercur Hill, according to the statement of Mr. R. C. Hills,[1] which is confirmed by the observations of the writer, the gold-bearing horizon is about 150 feet above the top of the Silver ledge. On Marion Hill it appears to be considerably less, the average distance between the two deposits, as shown by the difference of altitude between the Carrie Steele and the Marion workings, being, according to the detailed survey of Mr. Frank Anderson, approximately 100 feet. In this latter locality, however, there are a multitude of small faults, which make the actual difference between the two horizons rather uncertain.

Like the Silver ledge, the Gold ledge follows a sheet of Eagle Hill porphyry, of slight thickness and usually in greatly decomposed condition. Owing to this decomposition, it is not easily recognized as porphyry, nor even as an igneous rock; indeed, its true nature was first detected by the writer only after he had been some little time in the field. The field evidence of its nature may be briefly indicated as follows:

1. The general megascopic character of the decomposed rock of the gold horizon, especially where only slightly or not at all mineralized, is exactly that typical of altered porphyries as exhibited at other mining districts, such as Leadville. There is a superficial difference, owing to the great dryness of the climate at Mercur; for this reason the altered porphyry does not usually contain any water, and hence does not assume the clay-like form known as "talc" by the miners.

2. This altered porphyry in the gold horizon is identical in appearance and characters with the altered porphyry of those portions of the Silver ledge below which have escaped the effects of the Silver ledge mineralization.

3. This zone can be traced continuously from the above-named hills along the outcrops in either direction, but especially to the southwest, through the various stages of less alteration to the comparatively fresh rock which contains phenocrysts and has a firm consistency and rough texture. This unaltered rock is part of the main sheet of Eagle Hill porphyry, which apparently owes its fresh condition to its greater thickness and consequent freedom from weathering except along the edges.

---

[1] Ore deposits of Camp Floyd district, p. 3.

Into this same main lower sheet the altered porphyry of the Silver ledge can be followed.

Microscopic study has supported the conclusion derived from field evidence, in showing that the altered rock of the Gold and Silver ledges is a decomposed porphyry identical with the porphyry of the main sheet. This conclusion has already been stated in the preceding chapter, namely, that the main sheet of Eagle Hill porphyry splits, just southwest of Mercur Hill, into three thin sheets, of which the lowest is the thickest and the uppermost the thinnest; and that the lowest is characterized by the occurrence of silver ores, while the gold ores are confined to the middle of the three, and the uppermost has not been mineralized to any important extent.

The gold of the ore is invariably invisible, no one ever having claimed to have found a grain of the metal; the richness or entire barrenness of a sample, therefore, can be gauged only by assays. When richest, the ore generally has a loose, pulverulent gangue, which consists mainly of quartz. Associated with it is arsenic in the form of realgar; also cinnabar and iron pyrites. Barite, calcite, gypsum, and Chinese talc are found in the ores, but are not believed to be closely connected genetically with the gold mineralization.

Recent atmospheric changes have altered those of the gold ores which are most exposed, so that there are two distinct classes, considerably different in the nature of the rock and the mineralogical character of the ores, as well as in their economic importance. Among the unoxidized ores, those on the property of the Golden Gate Mining Company are the most important so far discovered. The exploration there has been very slight, so that there is no good opportunity to study this important class of ores; but as the sulphides are plainly the original form of all the ores, it will be necessary to describe their occurrence in the Golden Gate.

GOLDEN GATE MINE.

The explorations on the Golden Gate property at the time of examination consisted chiefly of two shafts, a short distance apart, a little above the town—the north or Mabel shaft, and the south or Grasshopper shaft.

MABEL SHAFT.

The north shaft of the Golden Gate is about 136 feet deep. It starts on an outcrop of the barren limestone which lies above the ore-bearing zone, and continues in it down to the bottom of the shaft; the ore is encountered in a drift leading southward from the bottom. The material exposed in the shaft, which is not timbered (the dryness of the climate renders very little timbering necessary in this district), is limestone, often considerably decomposed, and evidently broken and disturbed. The average dip in the shaft seems to be about 15° southwest.

The drift at the bottom runs a little east of southeast, across the strike and in the direction of the dip. This drift is 127 feet long. It starts in limestone, which is hard in places, but in others is somewhat decomposed, probably by surface agencies. At a little distance from the shaft there appears in the drift a more altered zone in the limestone. This is siliceous and broken, and is somewhat mineralized, forming a low quality of ore. Above this is a zone of altered limestone, but softer and containing less silica than the one just mentioned. It yields easily to the pick or hammer, and probably a large part of its lime is replaced by silica in incoherent grains. There is some pyrite and a small quantity of gold, but less than that of the broken zone below. Following this is an actual thickness of about 6 feet of the cherty and broken, altered limestone, like that first mentioned. This is also a low-grade ore, of about the same value as the first. Above this again is an actual thickness of about 10 or 15 feet of altered limestone, dark-gray in color, and still retaining the characteristic structure, rough in texture and crumbling easily. Although considerably altered, this appears to be only slightly mineralized, and contains little gold. At the end of the drift a raise goes up vertically 22 feet, which near the bottom runs into a soft, black, fissile rock resembling shale, and so termed by the miners. It is somewhat different from the dark-gray altered limestone below, although of the same color, and, like it, is soft. The rock in the raise is smoother in texture, and is more markedly fissile. This fissile structure, however, is probably not an evidence of original stratification. It is rather of that nonpersistent, slightly irregular variety which is so common in residual as well as in sedimentary clays, and which often owes its origin to causes operating since its formation. This rock is, from the top to the bottom, greatly mineralized, being especially marked by the abundance of realgar; it contains also a considerable quantity of finely disseminated iron pyrites, and a much larger amount of gold than any in the lower zones, averaging probably half an ounce to the ton of ore. At the top of the raise the shale gives place rather suddenly to a hard, blue, unaltered limestone, which is absolutely barren. Of this only about a foot is exposed. There is here, therefore, a very fairly defined zone of ore about 20 feet in thickness.

GRASSHOPPER SHAFT.

The south shaft has a depth of 64 feet. For 46 feet from the top it is in limestone, which is somewhat broken and shows the effects of surface disintegration; it then cuts ore of the oxidized type, such as is found in the Mercur and the Marion mines. This ore is soft and pulverulent, light yellowish or grayish in color, and contains no pyrite, realgar, or other evidence of mineralization. The presence of gold is shown only by assay. The ore is about 10 feet thick; in the drift a few feet away it is found to actually pass into unoxidized sulphide ore, from which it is therefore directly derived. The bottom of the shaft is in limestone under the ore. This rock is somewhat broken and decomposed, has a northwest strike, and a dip of 20° or 25° to the northeast.

A drift running northwest from the shaft cuts, in a short distance, a sulphide ore exactly like that in the Mabel shaft, and containing a very large amount of realgar. The thickness also is about that of the ore in the Mabel, so that it is evidently the same sheet, and is probably continuous between the two localities. The drift runs through the zone of ore into hard limestone above, and at the end a raise goes up 40 feet without finding any change in the character of the rock. There appear to be rather more bands of hard material in the ore here than in the north shaft.

The so-called "black shale" in the Golden Gate mine, with which the ores are associated, probably results, in part at least, from alteration of the thin sheet of porphyry before mentioned. It is on the same horizon as the other ore deposits, and the analysis of the Golden Gate ore (p. 424) shows a considerable amount of the alkalies, indicating the presence of feldspathic constituents, such as are contained in porphyry.

From the Golden Gate shafts the outcrop of the gold ledge has been followed southward nearly continuously, and is marked by shallow prospect holes. It shows a small amount of mineralization for most of the way up Mercur Hill as far as the Mercur mine. Although the oxidized rock is undoubtedly more profoundly altered from its original condition than that which contains the sulphide ores, yet in the latter the process of mineralization and the deposition of the sulphides have evidently had a disguising effect, making the difference between the altered porphyry and the altered limestone unapparent without careful study, so much are the original characters of both replaced by the characters induced by the mineralization which both alike have undergone. But with oxidation most of the sulphide ores, especially the abundant arsenic-sulphide and pyrite, are decomposed and leached out, so that the original difference between the porphyry and the limestone is better shown, though it is by no means always clear. It is for this reason that the outcrop of the Gold ledge porphyry can be followed with a certain degree of ease, and for this reason also the oxidized ores offer quite as favorable opportunities for study as do the sulphide ores from which they are derived. It is in these oxidized ores, moreover, that most of the exploitation work has been done, since they are easily reduced. They readily yield up their content of gold to the dissolving influence of cyanide of potassium, and from these solutions it is precipitated by metallic zinc. Such is the condition of the gold in the sulphide ores, however, that the cyanide solutions are comparatively ineffective. The sulphur must first be driven off by roasting, which is practically equivalent to the slow natural process of weathering, and in this roasting there is said to be a marked loss of gold. For this reason their reduction on a large scale has not yet been attempted, though probably they will be mined and successfully treated in the future.

In the oxidized ores a large amount of mining has been done in the Mercur mine up to the present time; indeed, larger than all the other workings in the district. In this mine, therefore, most of the data in

MAP OF UNDERGROUND WORKINGS OF MERCUR MINE.

Figures denote elevations referred to datum at mouth of Ruby Tunnel, assumed as 6,000 feet.

Scale: 75 feet = 1 inch.

regard to the detailed structure of the gold deposit have been obtained, the owners and superintendent having lent their aid in every way to its full investigation. The Mercur ore bodies will therefore be described in considerable detail.

MERCUR MINE.[1]

UNCLE SAM TUNNEL.

This is the most southerly in the series of tunnels in the Mercur mine which have been or are actually productive of ore. The mine is

Fig. 42.—Banding in altered porphyry.

opened by means of these tunnels, which are driven into the side of the hill at the outcrop of the altered zone along the strike of the beds. The mouths of the tunnels, viewed from a distance, afford a very good indication of the position of the ore sheet.

At the entrance to the Uncle Sam tunnel the open cut shows at the top a thickness of 4 or 5 feet of soft, shaly stuff, of various alternating shades of brown, gray, and yellow. This is undoubtedly altered Eagle

[1] Geological sections through the principal workings of this mine may be found on Pl. XXXIV, p. 418.

Hill porphyry. It is the characteristic roof of the ore sheet, and among the miners goes by the name of "shale." Immediately below this altered porphyry zone comes decomposed limestone, containing about one-third in bulk of soft, pulverulent stuff, which incloses bowlders of hard, blue lime and of chert, making up the other two-thirds of the rock. The bowlders have been formed in place by decomposition extending from the fissures and joint and bedding planes inward; and the gray pulverulent matter which surrounds them is the product of their alteration. It is very much like the product of the alteration which takes place under atmospheric influences, such as has already been noted in the general description of the limestones of the district. There is only about 5 feet in which the proportion of the altered to the unattacked limestone is as above indicated, for the alteration grows less as the distance from the porphyry increases. The limestone gradually becomes more massive, and the rounded bowlders give place to large square blocks, separated by narrow zones of decomposition, some of which run parallel with the bedding and some perpendicular to it. The strike of the limestone here is about N. 55° W., and the dip is 12° NE. In the least-altered limestone at the bottom of the cut are numerous empty fissures, vertical, and averaging in direction about N. 30° E., although varying from N. 10° E. to N. 60° E. These range from mere cracks to fissures 2 inches wide. They do not exist in the altered limestone, but their continuation can often be traced through it by lines of greater decomposition than the rest of the rock. In the decomposed, yellow, shale-like rock above there is no evidence of them. That these fissures are not of very recent origin, such, for example, as might be caused in surface rocks by blasting in the process of excavation, is shown by the fact that there is commonly on their walls a thin coating of crystalline calcite. Thus, in one fissure, at a point where it is an inch in width, there is a coating of calcite on either side, between one-sixteenth and one-eighth inch thick.

At 25 feet from the mouth of the tunnel the shaly stuff loses its fissile character, becoming massive and divided by planes of fracture into blocks. It is still soft, however, and bears evidence of great decomposition. It is generally stained yellowish, with occasional residual patches of light gray. In some zones, however, it becomes thin-banded and much broken, as in the outcrop. It seems, therefore, that the shaly and banded variety of this altered porphyry is directly due to oxidation at the surface, and that the massive form is more nearly the original; and the residual patches of gray material recall the "black shale" of the sulphide ores. As a matter of fact, there are in this mine, as will be seen later, many places where the process of oxidation is actually going on, by which a dark-gray ore carrying sulphides, in every way identical with the ore of the Golden Gate, is changed to the light-gray massive variety or to the banded, light-colored, fissile rock.

The zone of altered porphyry, although in a general way conformable with the bedding of the limestone, shows many local irregularities; so that the contact rolls up and down along the course of the tunnel, while the general direction of the limestone remains constant. Near the mouth of the tunnel the contact curves down across the bedding from the roof almost to the floor, and after running along on a level for a short distance, curves upward again and disappears above the roof, just beyond the first cross-cut to the east, which leads to the Nimrod stopes. At this point the altered limestone, with its characteristic decomposition bowlders, is not present, but the massive altered

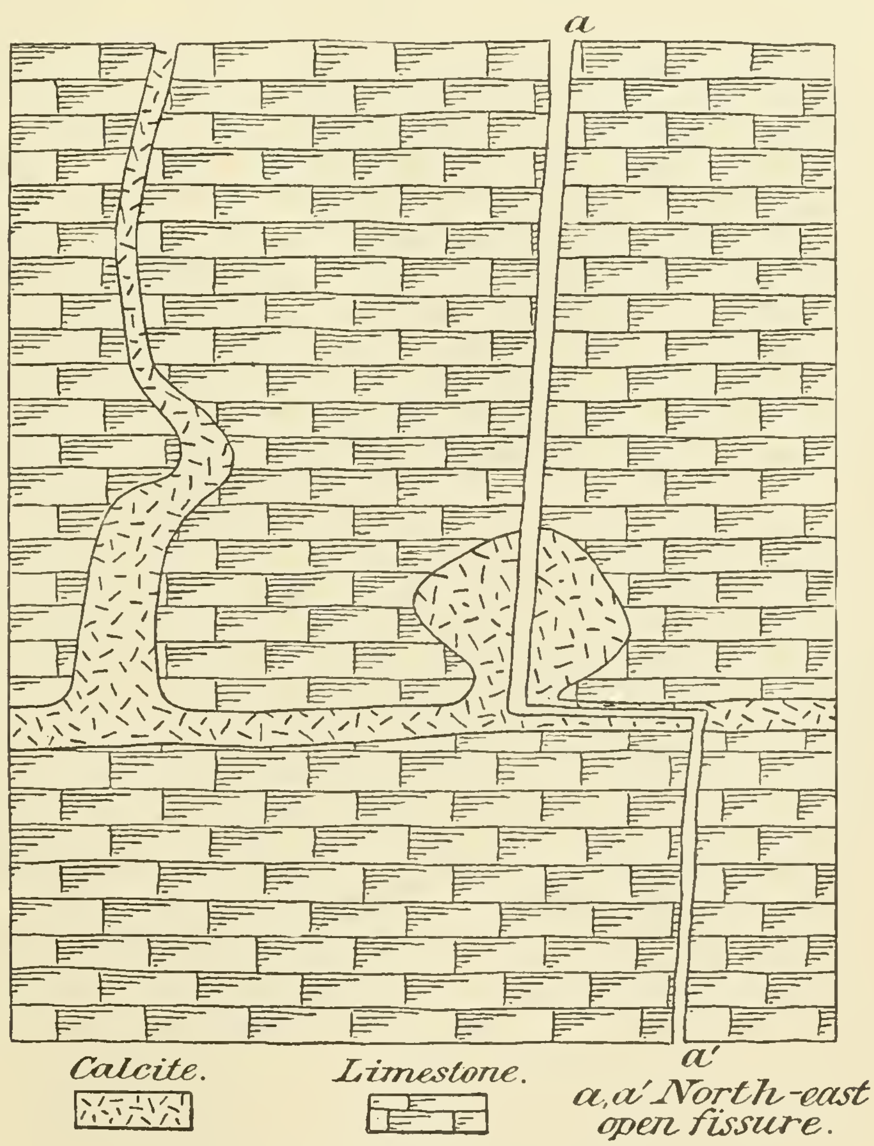


FIG. 43.—Open fissure cutting and deflected by calcite vein.

porphyry rests directly upon comparatively fresh limestone, containing vertical northeast open fissures. Besides these open fissures there is a distinct set of fractures which are filled with crystalline calcite, and which evidently belong to an earlier period of formation. Wherever these two sets of fractures occur together, not only in this mine but anywhere else in the district, the same relation in point of age is noticed between them. The older are entirely filled with coarsely crystalline calcite, and appear in general to be nonpersistent. The smaller are simply gash veins, and may be seen to thin out and disappear at both ends on the walls of the drifts. The larger are often 2 or 3 inches wide, and in places along their course bulge out into irregular shapes, as if waters which coursed along the fissures had here fashioned spaces by their corrosive power alone. These irregular spaces may be a foot or more in diameter. The veins vary in trend from about N. 10° W to N. 60° E., but average N. 20° E. in trend, and hade about 80° W.

The empty cracks and fissures mark a period of sheeting of the rock which was evidently posterior to the formation of the calcite veins just described. In trend and hade these later fissures are approximately similar to the calcite veins; but they are much more persistent in their nature, since they usually run from the top to the bottom of the drift, with no evidence of diminishing in either direction. Some of the smaller cracks have quite bare walls, but there is usually a thin coating of calcite, with small crystals projecting inward from either wall. This lining usually takes up only a very small portion of the space, so that nine-tenths of the crevice is empty, although in the smaller ones often much less. The paucity of the calcite and its irregular distribution, as well as its thicker deposition at the opening of small, irregular crevices in the limestone which run into the main fissure, show that it has been deposited under comparatively dry conditions. The fissures often follow along the course of a calcite vein, this evidently offering a zone of less resistance to the second strain. Sometimes the crack runs in the middle of the calcite, but more often on the side, so that on one side of the later fissure is the limestone wall and on the other the older vein. Sometimes, also, the crevice cuts through one of the large, irregular spaces of calcite which have been described as connected with the veins. (See fig. 43.) These phenomena are mentioned as showing the later age of the open fissures.

In the stopes on both sides of the main tunnel, ore has been taken out, usually from a point about 10 feet below the altered porphyry to the top of it, stopping at the hard limestone above. The thickness of this altered porphyry here is not far from 15 feet, so that the total thickness of rock removed is 25 feet. Often, however, it has been taken out only as far up as the bottom of the altered porphyry or "shale," which often constitutes the roof, so that here the thickness of material removed is only about 10 feet. The chief ore, therefore, is that somewhat decomposed zone of limestone, often containing bowlders of decomposition, which immediately underlies the altered porphyry. In some places this contains considerable chert; in others, no more than the ordinary limestones of the district. Above, the altered porphyry may be sometimes richly enough impregnated with gold to be available as ore, but hitherto this has quite as often not been the case. Usually the mining stops at the lower contact of the altered porphyry, leaving a clean and quite regular wall; and in every case it must stop at the upper contact of the porphyry with the limestone, and this in turn gives an even wall, for the limestone is generally quite barren. Below, the mineralization extends irregularly and gradually into the limestone, and therefore the floor of the ore bodies, as shown by the excavations, is irregular. The average thickness of available ore is perhaps about 7 feet.

NIMROD NO. 2 TUNNEL.

The stopes near the mouth of this tunnel, which is next to the Uncle Sam, proceeding along the outcrop down the hill, connect on one side with the Uncle Sam stopes and on the other with the stopes of the Nimrod tunnel. The general structure here is the same as described in the Uncle Sam stopes. The bleached and altered porphyry is sometimes shale-like and sometimes massive, and averages 8 or 10 feet in thickness. Below it the limestone is often altered to a soft and crumbling condition, yet in places is still massive and of a light-brown color, so that it is very much like the altered porphyry in appearance. A convenient distinction between the altered porphyry and the altered lime, stone is the presence in the latter of small calcite veins, which are never found in the porphyry. This limestone is profoundly fractured by the same system of fissures that has been described in the Uncle Sam tunnel as northeast in trend and vertical in hade. So great is the fracturing throughout this whole tunnel that it is difficult to get the actual strike and dip.

A short distance from the mouth of the tunnel the same upward roll that was noticed in the Uncle Sam carries the decomposed ore-bearing horizon up above the drift, which passes into the hard limestone beneath. In the latter rock are some very large northeast open fissures, which are persistent from the top to the bottom of the exposure, and which, on account of the freshness of the rock, are very clearly defined. There are also some calcite veins having the same general direction, but they are rarely persistent along the whole height of the tunnel. At about 100 feet from the mouth is an intensely fractured zone, along which there is a most interesting alteration, and one which throws much light on the processes of mineralization. This zone is vertical and about 10 feet thick. It is characterized by a soft, black, massive rock, like much of that associated with the ore, and which the miners call black shale. This has no trace of horizontal structure, but in places the fractures have given it the semblance of vertical bedding. In the softer parts the fissures have been filled by the products of decomposition, and yet they can usually be traced without much difficulty; along the sides of some of the more open of them are almost continuous coatings of realgar. This soft, siliceous rock becomes recognizable in its harder portions as a softened and altered limestone, and on either side of the strongly fractured zone it so grades into hard limestone that it is impossible to locate any boundary between the two. It is evident that in this case the limestone is altered into one phase of the "black shale" which in the unoxidized condition contains the ore, and although no assay was made from this particular place, the presence of abundant arsenic and the results of other assays made later from similar localities show that this also is probably an ore. The flat-lying ore horizon, with the altered porphyry for a roof, is out of sight, above the top of the tunnel, and this vertical tongue of ore extends from the flat-lying zone downward into the limestone. It evidently follows a set of the open northeast fractures, which mark a strongly sheeted zone, and the mineralizing agents have followed this zone, depositing the characteristic sulphides of the gold horizon and changing the limestone to the "black shale," which is the typical gangue of the unaltered ore.

At about 185 feet from the mouth the tunnel turns and runs nearly at right angles to its former course. Just before turning the corner, a raise shows, about 15 feet above, the massive light-colored rock, often banded red and yellow, which is probably the altered porphyry; at the turn the altered porphyry comes down into the tunnel, and stopes lead down to the Nimrod workings. The limestone below this is broken and cherty, and the contact between it and the altered porphyry is sharp. The porphyry itself shows all the different varieties which are found connected with the ore. Much of it is massive and black, very slightly fissile. This variety is hardly distinguishable from the rock of similar appearance which is derived from the limestone by alteration; and, as in the Golden Gate mine, the explanation must be that the same process of mineralization, and the deposition in both of the same minerals, have made from these two originally dissimilar rocks products which appear to the eye almost exactly alike. Here there are patches and irregular bands of light brown, which appear to be residual, since they are often surrounded by the soft black rock. In many other places the black rock is surrounded by the light-yellow rock, with red and greenish bandings, which has before been noted as characteristic of the altered and bleached porphyry of the Gold ledge. One place shows beautiful, nearly vertical, red and yellow bandings, trending northeast, or parallel to the general direction of the fracturing. There appear to be here, then, the three most typical stages in the alteration of the porphyry as found at the horizon of the gold ores: First, the light-brown, massive, somewhat decomposed variety, which outcrops along this horizon in places where it has not been mineralized, and is similar to the altered Eagle Hill porphyry at other horizons. Second, the dark-gray "black shale" of the miners, which sometimes surrounds the first type and is evidently derived from it. As already stated, this rock is due to the processes of mineralization. The analysis by Dr. Hillebrand of dark ore like this discloses the presence of a considerable amount of finely divided and disseminated iron pyrites, in such fine particles as often to be megascopically invisible, and this probably gives, in part at least, the black color to the rock. This pyrite was probably introduced at the time of mineralization, and accompanies the gold and other characteristic minerals. Third, the type which is so common in the oxidized zone of the gold ores, the light-colored banded variety. The derivation of this variety from the massive, black, mineralized rock just discussed has been observed in innumerable places, and is seen to be due simply to the effects of surface oxidation, whereby the sulphides are decomposed, partly leached away, and partly concentrated as oxides in the irregular bands which sometimes give it the simulation of bedding. This simulation, however, is destroyed on the slightest attentive observation, for the bands are rarely horizontal for any distance, or even continuous in any one direction, but become curved and sinuous, often being arranged in concentric circles (see fig. 42). The bands are, therefore, simply the concentration of some of the colored oxides in zones of slight weakness formed in the rock by the contraction attendant on the loss of a part of its bulk by weathering.

Toward the end the tunnel follows several narrow and nonpersistent streaks of soft, decomposed material in the hard limestone below the main ore-horizon. These streaks fade out into the hard limestone in all directions, and are evidently due to its decomposition, in the same manner as are the vertical zones along the fracture planes. They are here, however, very slightly or not at all mineralized.

NIMROD TUNNEL.

This follows the same horizon, next the Nimrod No. 2 tunnel. The entrance is in the broken limestone which lies under the altered porphyry, but in a short distance a roll in the porphyry brings the latter down into the tunnel. In raises it appears to be in thin sheets, with altered limestone and chert between, and hard, brown, altered limestone above, which soon changes to the blue unaltered rock.

In the first raise, on the right hand, are found barite veins in the altered cherty rock. Although these are numerous, they have no predominant direction; they are not persistent, but form irregular bunches, and penetrate the rock in every direction, being entirely similar in habit to the barite in the Silver ledge. Like the rock in which they are found, these veins appear to be considerably decomposed. They crumble easily, and are inclosed in a gray powder, which seems to be the product of the decomposition of the limestone in which they were once embedded. This powder, falling out, very often leaves the crystals of barite entirely isolated. As this decomposition evidently accompanied the introduction of gold in the ores, the barite could not have been deposited at the same time, but must have existed in the rock prior to this mineralization. On the other hand, it has every indication of an origin similar to that of the barite of the Silver ledge, and may well have been deposited at the same period.

The shale is partly black, partly light and banded. The limestone immediately below is so broken that neither bedding, distinct fracture planes, nor any other structure can be made out. It is much altered, with bowlders of residual hard limestone, and has the appearance of being good ore. Beyond the stopes it becomes harder, and it is then seen to be traversed by many vertical northeast open fissures. In places there are also many small, nonpersistent calcite veins, which sometimes carry realgar. This is rarely the case where the vein is already quite full of calcite; but where the calcite has only partly filled the fracture, or where a solid vein has been traversed by a later crack, realgar is found forming a coating upon the calcite, on both sides of the fracture. In one case noted a calcite vein was cut at right angles by a narrow open fissure, the sides of which were coated with realgar. This coating extended through the calcite vein, but the rest of the calcite carried none of it.

At the end of one of the barren drifts a flash-light photograph was taken, showing a very perfect set of the persistent open fissures in the hard limestone. (See Pl. XXXII.) They are here in their general north course; the walls are nearly straight, and bear little evidence of corrosion or erosion. The limestone near a large fracture is generally so much sheeted that it falls out easily, and to this the widening of the original sheeted zones is probably due, rather than to any dissolving action subsequent to the formation. It is not probable that at the time of formation these zones offered any such large open spaces as at present, when some of them are wide enough to admit an arm. The walls of these fissures are sometimes crusted with gypsum, and with calcite, from which the alteration to gypsum is to be observed. These crusts are not continuous; and their formation by slow exudation under comparatively dry conditions, rather than by deposition from freely circulating waters, is shown by the fact that wherever a slight crack having a different course from that of the fissure runs into it its junction with the main fissure is marked by a slight but prominent ridge of botryoidal calcite, while the adjoining surface has only a mere film. On these ridges the outside is usually gypsum and the inside calcite, although sometimes it is all gypsum.

From the stopes the main tunnel runs below the ore horizon into a hard blue limestone containing calcite veins. At some distance it enters a vertical zone of ore, similar to the one described in Nimrod No. 2 tunnel, but more extensive. Here the tunnel turns, and follows this zone to the breast. The altered rock is marked by multitudinous parallel fractures, running about N. 30° W., a direction somewhat different from the ordinary trend, and dipping 75° SW. Along these fractures the limestone has been completely altered, for a width of about 5 feet, to the typical "black shale" of the gold ores. In some places, moreover, it has been oxidized to the light-colored, banded variety, the bands being commonly parallel to the direction of the sheeting. The cracks, fissures, and small interspaces are filled with realgar. On both sides of this altered zone is the hard, little-altered limestone, and in

FACE OF DRIFT IN MERCUR MINE.
Showing fissures in hard limestone of Gold horizon.

some cases a single strongly marked vertical fracture separates the hard limestone from the soft arsenical rock. The calcite veins which occur in the hard limestone are present in the altered zone, but they are entirely changed to gypsum. In some cases a vein which is at one end entirely of gypsum passes out of the altered zone and becomes at the other end of pure calcite. Residual bowlders of the hard limestone are occasionally found in the very midst of the soft ore. As the tunnel follows this zone, the alteration and mineralization gradually decrease, till at the breast it has nearly disappeared. The fissures are still present, and wider than before, and it may be due to this fact that there is no mineralization along them. Observation in various parts of the mine show that where these fissures are the widest the mineralization is generally very small. On the contrary, it is in places where the rock is greatly sheeted and the individual fissures are narrow that the mineralization has been greatest. It is as if the agents which produced this result were detained in the passages where the circulation was less easy, while they passed so rapidly through the larger canals that they had little effect. The fissures at the breast of the tunnel trend about N. 10° W., showing a return toward the more usual direction, and have a hade of about 75° W.

At about one-third of the distance from the point where the tunnel runs into the mineralized zone to the breast a raise has gone up on the vein for about 50 feet. It was found that the mineralization became less along this raise, so that it was discontinued. It is not impossible, however, that a continuation of it would have revealed the existence of a larger body of ore above.

In the Nimrod stopes, which are very extensive, ore has been taken out in a continuous sheet, varying considerably in thickness. This irregularity is due mostly to the irregularity of the mineralization in the limestone which constitutes the floor; the roof is in general uniform.

MERCUR TUNNEL.

This tunnel adjoins the Nimrod on the east. It starts in the somewhat broken and altered blue limestone, at a little distance below the chief ore horizon. About 20 feet above the mouth there is an open cut (see Plate XXXIII), exposing the characteristic gold-bearing horizon. Here is seen the thin sheet of altered porphyry, bleached and almost crumbling, and below it the altered limestone, consisting of gray powder, which incloses decomposition bowlders of harder rock. A small tunnel connects this open cut with the Mercur stopes.

The altered porphyry comes down into the roof of the main tunnel at a point about 40 feet from the mouth; below this is broken and cherty limestone. At about 100 feet there are in this cherty limestone many large veins of barite, some of them nearly a foot wide. They are characteristically parallel with the bedding, although some of the smaller ones are vertical, and many spread out through the rock in no particular direction. The largest are at the contact of the altered limestone and the altered porphyry; none were seen to enter the porphyry. The cherty rock and the character of the barite veins strongly suggest the Silver ledge, although the chert is broken and somewhat decomposed, and seems to have undergone a later alteration, which is evidently that of the Gold ledge mineralization. In many of the veins open cavities are found, into which the crystals of barite project. These were, perhaps, formed by the decomposition of a part of the limestone which originally filled them, or they may have been left at the time of the deposition of the barite; this latter condition is often found in the unaltered barite of the Silver ledge. On the walls of these cavities cinnabar is often found in small quantities lying upon the crystals of barite. It seems probable that at the time of the secondary mineralization these minerals were deposited on the barite where open cavities already existed, and that the barite itself was formed at the time of the primary mineralization which produced the ores of the Silver ledge.

Farther on there are many small calcite veins in the limestone, but they all terminate abruptly on reaching the altered porphyry. This limestone is not so broken or so cherty as near the mouth of the tunnel, where the barite veins are found. For a considerable distance there is exposed at the bottom of the tunnel about a foot of hard blue limestone, which lies under the most altered and mineralized zone. This is traversed by vertical fractures, and along the bedding planes often becomes soft and black; it also carries a small quantity of realgar. At about this point a winze goes down 50 feet in hard, unaltered limestone, showing that the mineralization does not extend downward. From here the tunnel runs on in generally hard limestone, always apparently below the main ore sheet; but in a short distance a turn in its course brings it nearer the ore horizon, and the limestone begins to be irregularly altered in places to the arsenical ore, yet without any brecciation or any change in the attitude of the beds. Every stage of the change from the solid, hard limestone to the soft, decomposed material, which is identical with a large part of the "black shale" of the main ore horizon, can be traced; but in this case these softer portions are usually surrounded on all sides by the hard limestone. Predominant fractures trend N. 10° E., and dip 75° W., and their walls are generally coated with arsenic. Farther on, the whole rock is mainly changed to the decomposed variety, which still carries realgar and some cinnabar, but is massive and has no fissile structure. Farther on still, the zone of broken and cherty limestone, which is typical of the ore belt, comes in over the soft, altered limestone; and yet farther, the light-colored massive rock, which probably represents the altered porphyry, comes in in its usual place above the cherty zone. A change in the direction of the tunnel with reference to the course of the porphyry causes the porphyry to rise again to the roof and disappear within a few yards.

OPEN CUT ON GOLD LEDGE, MERCUR HILL, NEAR NIMROD TUNNEL.

Then comes, in the reverse order, the same succession which has been described: first, the zone of broken and cherty limestone, and then the soft, black, arsenical, altered limestone. There is of this about 15 feet. The contact then rises, and the tunnel runs for 50 feet with the altered limestone above and the hard blue limestone below. The rock above carries gypsum veins, while that below contains veins of calcite, and often one runs directly into the other, showing that the gypsum has been formed by alteration of the calcite, as the soft rock has been formed by alteration of the limestone. In some cases a crack whose sides are coated with realgar traverses a vein of gypsum; sometimes a realgar vein of this sort may pass through both gypsum and calcite. This does not necessarily show that the gypsum was formed as a vein before the introduction of the realgar, but only that the calcite veins were formed earlier than those fissures which carry realgar.

In the stopes connected with the Mercur tunnel neither the altered porphyry nor the altered limestone is fissile, both being massive or pulverulent. In that part of the stopes which is nearest the surface and which connects by a short tunnel with the open cut above mentioned, there is exposed about 5 feet of altered porphyry, brown in color and broken into irregular blocks, which by weathering have become marked with usually concentric bands of brighter color. Above this is altered limestone, some of it entirely decomposed to a gray powder; below, the limestone is altered in the same manner, with harder residual bowlders inclosed, which are sometimes of unaltered blue limestone. This altered limestone carries considerable earthy, scarlet cinnabar, and is a very good gold ore.

APEX TUNNEL.

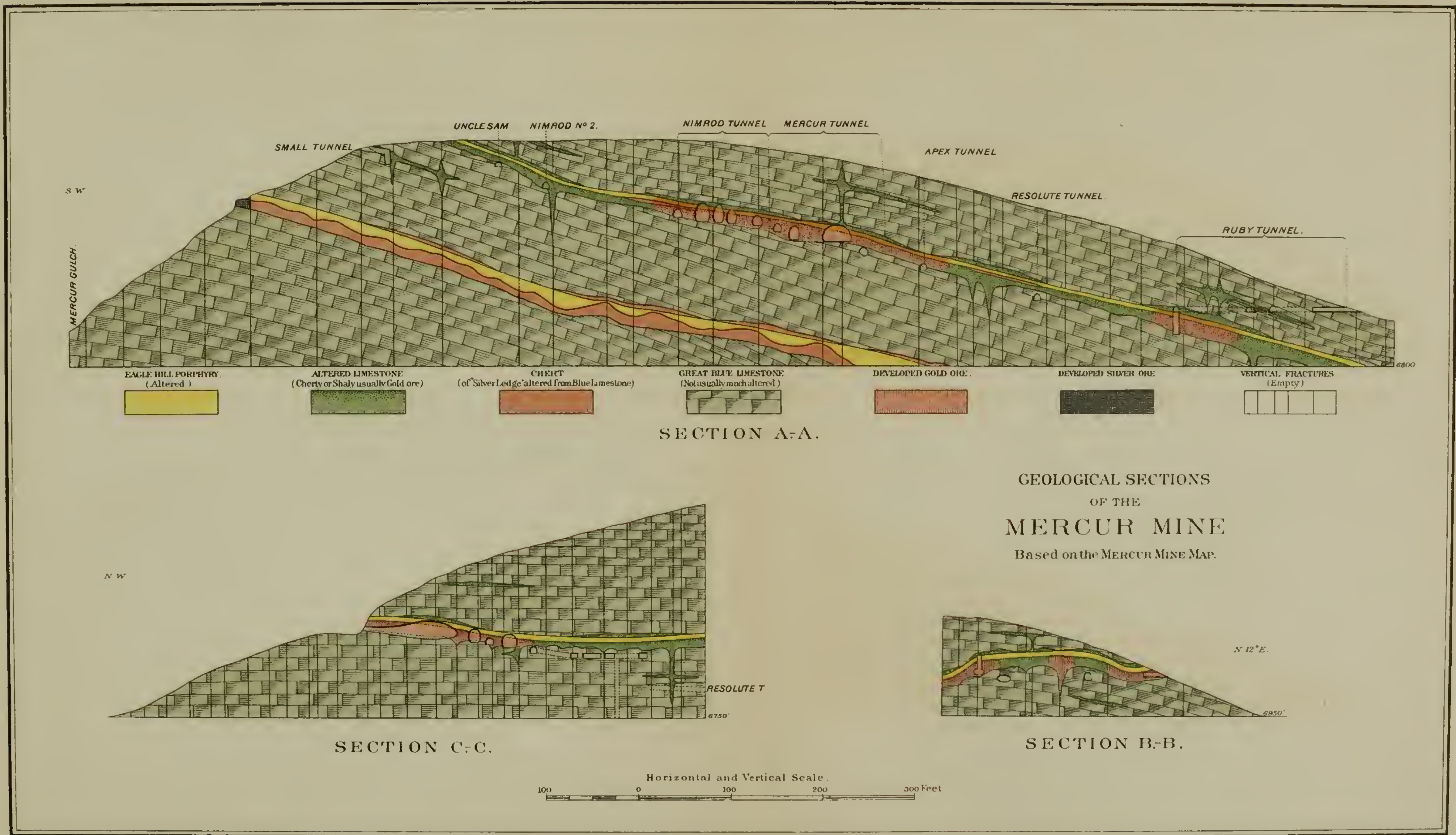
This tunnel starts in above the ore, in hard blue limestone, somewhat fractured, and runs into the ore horizon at a distance of about 50 feet. At this point stopes about 10 feet high run under the floor of the main tunnel. Above is a brown, massive rock, which may be the altered porphyry, and below this is exposed 5 or 6 feet of broken cherty limestone, carrying barite in irregular, generally horizontal, veins. Farther on the ore horizon rises gradually, so that it passes above the roof of the drift. The great stopes at the end of the main tunnel are all in hard and little-altered limestone, with only small areas of decomposition along some of the joint and bedding planes. It is, nevertheless, a very good ore. None of the soft, altered, arsenical limestone is present, and none of the altered porphyry; the roof and the floor present no especial difference from the stoped-out rock. It seems very possible that the altered porphyry and the cherty zone which mark the typical ore-bearing horizon may be above the roof of the stopes. With this idea in view, a sample was taken of the limestone at various points on the roof, as far up as any material could be obtained. This was assayed by Mr. R. H. Officer and gave 0.82 ounce of gold to the ton, an ore fully up to the average of the mine. Below the point from which this sample was taken the ore has already been stoped out for an average thickness of about 10 feet, and continuously along this same horizon for some distance, except for pillars which are left standing to afford support to the roof.

Going up in the stopes toward the Mercur tunnel, we meet, near the tunnel, the cherty horizon again, which here carries considerable Chinese talc, entirely similar in nature and habit to that already noted in the Silver ledge. The stopes which run under the Mercur tunnel near its mouth, down to the Resolute tunnel, also contain, associated with the cherty material, considerable Chinese talc, along with cinnabar and some barite.

RESOLUTE TUNNEL.

This tunnel starts on the gold horizon, in the cherty zone. Near the mouth are many vertical open fractures, trending N. 20° E. At a distance of about 50 feet from the mouth is a light-gray, massive rock, several feet thick, which is probably an altered porphyry; it is well shown in the drift which runs down toward the Ruby tunnel. Immediately beyond the junction of this with the main drift the contact suddenly rises into the roof, and is not seen again in the tunnel. Just beyond this point the stopes begin, and ore has been taken out on the western side from the level of the tunnel floor up to a height of from 6 to 20 feet. Nowhere does the roof seem to be the decomposed porphyry which probably lies above, but a very slightly altered blue limestone, similar to the rock which has been stoped out. This seems to be a trifle below the normal ore horizon. Immediately after leaving the stopes, and proceeding farther into the tunnel, hard blue limestone is encountered, occasionally a little softened and carrying narrow vertical veins of realgar. The strike and dip here are respectively about N. 55° W. and 20° NE., but both are often obscured by vertical fractures, which are very numerous and persistent, and along which are sometimes found the coatings of realgar just mentioned. They vary in trend from N. 10° E. to N. 60° E. and dip about 70° NW. At the last Resolute stopes, which connect with the Apex stopes, a small quantity of ore has been taken out; overhead is a soft, irregularly decomposed rock, which is evidently an altered limestone, and not the altered porphyry that constitutes the true roof of the ore in general. If the altered porphyry is present it must be above the roof of the stopes.

From this point to the end of the main tunnel there is continuously hard blue limestone, without chert, but with frequent softer, decomposed patches of irregular shape, which grade into the unaltered limestone on all sides, and carry arsenic sulphide. In this limestone there are always northeast open fractures; there are also generally northeast-trending calcite veins, which are characteristically nonpersistent; but no barite. The latter mineral has been observed only in the cherty horizon directly underlying the altered porphyry.



GEOLOGICAL SECTIONS
OF THE
MERCUR MINE
Based on the MERCUR MINE MAP.

JULIUS BIEN & CO. LITH. N.Y.

RUBY TUNNEL.

In the incline which connects the Resolute with the Ruby tunnel the altered porphyry is shown in the walls, dipping at a slightly greater angle than the inclination of the drift. At the sudden turn in the incline this altered porphyry runs below the floor. From here to the main Ruby tunnel the incline is in altered limestone, very soft and shale-like in streaks.

The Ruby tunnel appears to have been started at a considerable distance above the main ore horizon. At some distance in, it cuts a streak of ore running conformably with the bedding. This streak is not very thick, and does not seem persistent. It is characterized by a very much decomposed gray rock, sometimes fissile and sometimes massive, which is probably an altered streak in the limestone, the result of the mineralizing solutions which have penetrated along the bedding planes; it may, however, represent a thin sheet of altered porphyry, and so be more similar to the main ore body. Some ore has been taken out of this streak, but it does not seem to pay for extensive stoping. The limestone below is broken and altered, and above it shows a fissile tendency. Level drifts which run in the direction of the Resolute tunnel show the ore streak rising to the roof and disappearing; and the limestone below becomes hard and unaltered, with many nonpersistent calcite veins, and open vertical fractures having a general trend of N. 10° E. At the end of one of these westerly-running drifts a winze has been sunk which reveals what is probably the main ore horizon. At a short distance below the floor of the drift is light-gray clay several feet thick, which is probably altered porphyry; below this is soft, black, arsenical rock, which is evidently an altered limestone. In this the winze goes down about 20 feet.

In the main tunnel the small ore streak which the tunnel follows rises to the roof after some distance and disappears. At the end the main tunnel is in hard limestone, and a winze has been sunk which reached the main ore horizon at a depth of 35 feet. This consists of a slight thickness of altered limestone, soft and black. Below this is 5 or 6 feet of light-colored clay, which is probably altered porphyry; and below this again the broken and cherty lime which constitutes, here as well as elsewhere, the chief ore-bearing zone.

MARION MINE.

The Marion mine was not examined with the same detail as was the Mercur, since there was no especial difference in the phenomena exhibited in the two; moreover, on account of impending litigation, the same facilities for investigating the mine could not be obtained. The following is the result of a brief examination:

The roof of the ore deposit can be traced nearly continuously, and can be recognized as an altered porphyry, less changed on the whole than in the Mercur mine; it is sometimes shaly in structure, oftener massive. The thickness of this altered porphyry varies from 2 to 20 feet; on the average it is about 5 or 6 feet. According to Foreman Jones, there is never any ore of importance above this zone, but sometimes the porphyry itself is sufficiently mineralized to be mined. As in the Mercur, the chief ore is the zone of cherty limestone immediately below the porphyry sheet. This is about 6 or 7 feet in thickness, and as a rule it is rather more altered than in the Mercur. In one place observed this limestone is comparatively barren of gold values, although altered and cherty and in every way resembling the actual ore, and although the usual roof of altered porphyry is directly overhead.

The most interesting point of difference between the Mercur and the Marion ore bodies lies in the even greater importance of the northeast fractures in the latter. The fracture zones are very abundant, and along many of them there has been a slight faulting. In all there are in the mine probably thirty or forty well-defined faults, varying in throw from 2 or 3 to 40 or 50 feet, the latter in one or two places only. In nearly every case the ore, instead of being cut off, follows the fault zone up or down to the corresponding horizon on the other side.

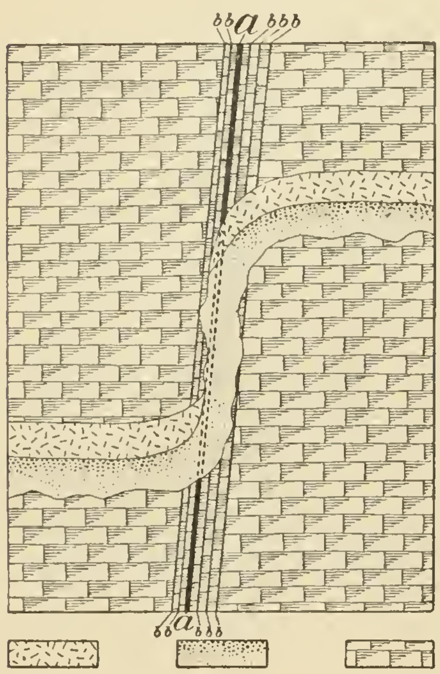


FIG. 44.—Diagram showing relation of ore to fault in Tunnel No. 3, Marion mine. *a, a,* chief fault plane; *b, b,* parallel fissures. Scale: 1 inch = 40 feet.

This is well exemplified in a fault seen in Tunnel No. 3. At the point examined this fault had a throw of about 40 feet, but according to Foreman Jones the throw is differential, being considerably greater at one end than at the other. All along the fault ore has been taken out for a width of 6 or 7 feet, leaving an open fissure connecting the flat-lying ore in the No. 3 workings with the flat-lying ore 40 feet above, in No. 2 tunnel, on the other side of the break. The fault zone is nearly vertical, and trends at this point about N. 70° E. The sheet of altered porphyry and the cherty limestone are cut off at the lower level and do not reappear until the other side of the fault is reached in No. 2 tunnel. The vertical zone which connects the two levels has not, therefore, all the usual characteristics of the ore. It is simply a softened and mineralized limestone, with hard blue limestone on both sides. Several places in the mine were noted which show the same phenomenon of mineralization along fracture or fault zones. This occurrence of ore is similar to that in the mineralized vertical zones in the Mercur, which also follow zones of sheeting, and differs chiefly in the fact that in the Marion the fractures are attended by notable displacement. Here the mineralization appears not to extend into the sheeted fault zone above or below the normal ore horizon on either side of the fault, but simply connects the two parts which have been separated by the faulting. The limestone above and below the part of the fault thus mineralized is much harder, and the individual fractures in it can be seen, which in the more altered portion have been filled by the products of disintegration.

As a general rule the ore in the fault fissures is of a poorer quality than that under the regular wall of altered porphyry. Its chief value, therefore, seems to be that it affords an indication of the direction of the ore horizon when it is broken by a fault; and thus is avoided much of the expense entailed in vain search for faulted ore bodies, such as is inevitable in most mines where a considerable degree of disturbance has taken place.

It does not seem probable that the ore in the fault zone represents part of that originally present in the normal ore horizon and which was simply dragged into the fractured zone at the time of the faulting. Its character is not such as to favor this hypothesis, being rather that of limestone which has been altered in place than that of brecciated material foreign to the wall rocks. The ore is apparently of about the same thickness and quality throughout the whole of the vertical zone; whereas, if it was derived from the flat-lying horizon and had been brought up along the fault, one would expect it to be thickest at either end, near the junction with the beds from which it was derived, and in the middle to be poorer or even absent. The inference, therefore, is that the mineralization which introduced the gold in this mine took place after the series of northeast fractures and the accompanying faults were developed; this is also the inference derived from the study of the relation of the ore to the open fissures of the same kind in the Mercur mine.

One large fissure in the Marion mine, along which no displacement has been noted, is several feet wide, but the most of this space has subsequently been filled by crystalline calcite. Since the deposition of the calcite there has been a further fracturing, as is shown by the existence of a large open fissure between the vein calcite and the limestone wall rock. In this later fissure the calcite on the vein side has assumed a very beautiful stalactitic structure. The same fissure extends downward into the Silver ledge in the workings of the Carrie Steele. Here it has been explored for some distance, the opening being large enough to easily admit a man. No ore of importance, however, has been found along this opening.

Some barite is found in the Marion gold ores, especially in cherty portions; also Chinese talc in similar localities. Cinnabar is frequent in the much-altered ore. Most of it is the bright-red, earthy variety, like that in the Mercur mine and elsewhere; a single specimen shows the dark-red, crystalline variety. This is the only specimen of crystalline cinnabar which was found in the vicinity of Mercur, and from its peculiar condition and the relations that it sustains to the calcite with which it is associated there is reason to believe that its age and the conditions of its deposition are different from those of the usual form of cinnabar. This special case will be mentioned later. (See p. 451.) Realgar was found forming crusts on calcite in veins which were not entirely filled, but retained a narrow open space in the middle. These veins occur chiefly in the hard blue limestone which underlies the ore.

GEYSER MINE.

The Geyser workings are situated on the northeast side of Marion Hill, on the same horizon as the Marion workings, but at a slightly lower elevation, owing to the dip of the porphyry sheet, which in both cases forms the roof. The ore revealed by these explorations is said to be of good quality, but up to the time of writing no gold has been extracted.

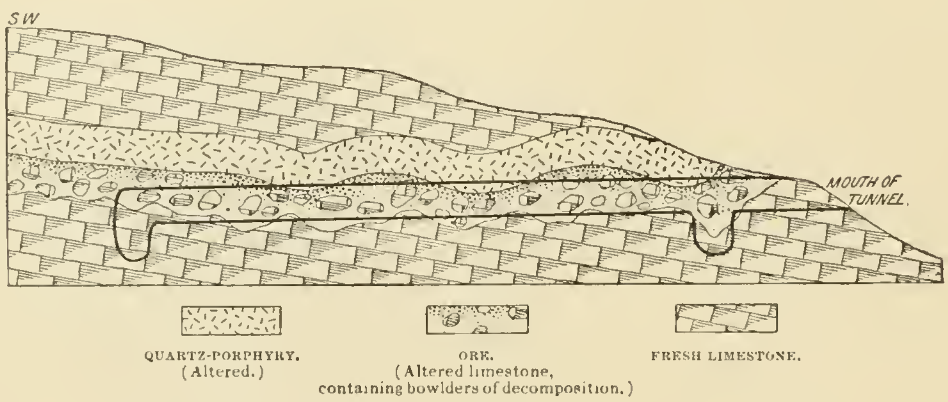


FIG. 45.—Section along Geyser tunnel. Scale: 1 inch = 40 feet.

In the open cut at the mouth of the main Geyser tunnel there is exposed the hard blue limestone, which at this point lies under the ore. The mouth of the tunnel itself is at the contact of altered porphyry and somewhat altered but still mainly hard limestone; the latter constitutes the ore, as elsewhere. The porphyry runs in a general way parallel to the bedding of the limestone, but locally often cuts across the bedding for a few feet, so that the actual contact is very wavy. The difference between the trough and crest of these waves is about 5 or 6 feet, and several are cut in the course of the tunnel. The very bottom of the porphyry is stained yellow and green for a few inches, and constitutes a low-grade ore. Above this zone it is massive and pearl-gray and shows only a trace of gold. Below the porphyry comes a broken contact zone, consisting mainly of brecciated limestone often silicified. There also appears to be a certain amount of altered porphyry in the breccia. This is the main ore body, which follows continuously the lower contact of the porphyry sheet and is said to be on the average about 12 feet thick. Below this zone there is usually a thin selvage band of altered shale-like limestone, which does not exceed 6 inches in thickness. This contains a little gold, but by no means enough to be classed as an ore. Below this is the same hard blue limestone as is exposed at the open cut, and this is quite barren. It will be seen from this description that the lower contact of the ore appears to be more sharply defined than is usual, and yet it is much more irregular than is the upper contact.

SURPRISE SHAFT.

The Surprise shaft is the deepest vertical working in the camp, and is a good example of the fact that not all of the ore horizon is mineralized, for while it has undoubtedly passed through the horizon along which the ore occurs in the Mercur and Golden Gate, all the rock thus far encountered has been practically barren.

The shaft starts in the lower shale belt and passes through this down into the hard limestone. The water which runs along the shale on top of the limestone accumulates in the bottom of the shaft to a depth of 30 or 40 feet even in the dry season. This is the only mine in the camp which contains water. Below the bottom of the shale, however, no water enters the workings.

Upper level.—At 125 feet from the top the first level runs off in a northwesterly direction (N. 25° W.) for 277 feet. Along the bottom of the drift is exposed a foot or so of altered porphyry like that in the other mines, but harder than in some. This is also exposed in the shaft below the floor of the drift, and is about 6 or 8 feet thick. Above the porphyry in the drift is decomposed limestone, stained and full of chert lenticules and nodules. This is the exact counterpart of the ore in the productive mines, but assays only a trace in gold. In the top of the drift is a thin streak of soft, shale-like rock, sometimes containing fragments of chert; this also seems to be decomposed porphyry. Immediately above this is hard blue limestone.

Lower level.—At 342 feet from the top a level runs in a generally northwest direction for about 100 feet. At the top of the drift is porphyry, decomposed and flaky; below this, at the mouth of the drift, is pulverulent altered limestone, stained green and yellow and containing much chert. This also is in all respects like the typical ore in appearance, but assays only a trace. At the bottom of the drift the limestone becomes very hard. The porphyry sheet is probably 4 or 5 feet in thickness; at the end of the drift a raise goes up 21 feet across the sheet, which shows an apparent pinching out. Below this drift hard limestone extends all the way to the bottom of the shaft.

RELATION OF THE SULPHIDE TO THE OXIDIZED ORES.

That the oxidized ores are derived from the sulphides by a simple process of weathering is a fact supported by abundant field evidence. In the Grasshopper shaft of the Golden Gate mine, as already stated, there appears a zone of ore in the oxidized condition, and farther down, in the drift leading from the bottom of the shaft, the same zone is encountered in the condition of sulphide. There are many places in the Mercur mine where a covering of the oxidized ore incloses a residuary portion containing sulphides, and the gradual stages of the transition are clearly shown.

ANALYSIS OF SULPHIDE ORE.

Following is a complete analysis of the sulphide ore from the Grasshopper shaft of the Golden Gate mine, by Dr. W. F. Hillebrand:

Analysis of Golden Gate ore.

	Per cent.
Silicon dioxide (SiO_2)	66.42
Titanium dioxide (TiO_2)	.85
Aluminum sesquioxide (Al_2O_3)	14.85
Iron sesquioxide (Fe_2O_3) } Iron protoxide (FeO) }	.31
Iron disulphide (FeS_2)	6.60
Manganese oxide (MnO)	None.
Calcium oxide (CaO)	.35
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.19
Magnesium oxide (MgO)	.83
Potassium oxide (K_2O)	2.73
Sodium oxide (Na_2O)	.13
Lithium oxide (LiO)	(*a*)
Water below 110° C	.53
Water above 110° C	3.65
Sulphur trioxide (SO_3)	.31
Phosphorus pentoxide (P_2O_5)	.04
Antimony pentoxide (Sb_2O_5)	None.
Arsenic pentoxide (As_2O_5)	.41
Arsenic disulphide (As_2S_2)	1.75
Molybdenum (Mo)	None.
Tellurium (Te)	*b* Trace (?)
Total	99.95

a Very strong trace.
b In the opinion of Dr. Hillebrand there was tellurium in the sample analyzed, although on account of the small quantity obtained he was unable to submit it to a special test, and therefore thought best to indicate this lack of certainty by the interrogation mark.

In its main elements this analysis is like that of an altered porphyry, differing chiefly in its content of arsenic and the traces of the rarer metals. The amount of alumina and the considerable quantity of potash and soda indicate the presence of a considerably altered orthoclase feldspar, while the magnesium and a part at least of the iron may well be derived from biotite. Leaving the arsenic out of consideration, the analysis can be almost exactly paralleled by the analyses of somewhat altered porphyries from other places, such as the White porphyry of Leadville. This bears out the result of field observations on the character of the ores in the Golden Gate mine already mentioned. According to these observations, some of the black sulphide ore of the Golden Gate is an altered limestone, while a part at least is an altered porphyry, and decomposition and the influence of the same mineralizing processes have given to both a common appearance, so that they can not be readily distinguished in the hand specimen. It was evidently from the altered and mineralized porphyry that the specimen analyzed was taken.

In examining the analysis a few things only are found which can not be referred for their source to the porphyry. The chief of these is the arsenic, which is evidently of subsequent and foreign origin, and which is here, as in the hand specimen, the chief indicator of the mineralization. In the hand specimen every little crevice is filled with this brilliant mineral, which occasionally becomes so abundant as to form the greater part of the bulk of a good-sized specimen. Ordinarily the appearance is not as if the realgar had replaced the country rock into which it has intruded, but as if the rock, shrunken from the effects of decomposition and the leaching out of a part of its volume, had afforded in its interspaces opportunity for the arsenic to crystallize. The specimen which was taken for analysis, however, was not one which appeared in the hand specimen to be rich in arsenic; that which was found may be regarded, therefore, as an average rather than an extraordinary amount. Undoubtedly all the arsenic was deposited as sulphide, and the small amount of oxide is therefore to be taken as the result of the alteration processes, which even in the sulphide ores have already begun. Besides the arsenic, the presence of a probable trace of tellurium is suggestive of the mineralization.

The amount of iron in the rock, chiefly in the condition of sulphide, but with a small amount changed to oxide, is not sufficiently great to justify the conclusion that it has a foreign origin identical with that of the arsenic. It is true that the fact that both are in the form of sulphides indicates that they were both reduced to this form at the same time and by the same agents; but this fact can be used quite as effectually to support one theory as another. There are no large bodies of pyrite in the ores; even aggregations of small size are rare. The mineral is disseminated in very small crystals throughout the ore, of which it therefore forms a generally inconspicuous part. It is far less characteristic of the mineralized rock than is the arsenic. The amount shown in the analysis may therefore be taken as a fair average of the content of the ores, and a corresponding amount of iron is not infrequently found in fresh porphyries, being contained in the biotite and other dark-colored silicates. Since in this case much of the most easily soluble elements, such as the potash and soda of the feldspars, has not been leached out, it is only natural that the iron of the original rock should remain, although as a result of the decomposition and the mineralizing agents it has been separated from the silicates and again concentrated in the form of sulphide.

ANALYSIS OF OXIDIZED ORE.

Following is the result of the analysis by Dr. Hillebrand of a sample of the oxidized gold ore, taken from the stopes of the Apex tunnel in the Mercur mine. This is in every way a typical sample of the best class of the oxidized ore.

Analysis of Mercur ore.

	Per cent.
Silicon dioxide (SiO_2)	89.24
Titanium dioxide (TiO_2)	.38
Aluminum sesquioxide (Al_2O_3)	2.02
Iron sesquioxide (Fe_2O_3)	1.45
Iron protoxide (FeO)	.62
Iron disulphide (FeS_2)	None.
Manganese oxide (MnO)	None.
Calcium oxide (CaO)	.95
Strontium oxide (SrO)	None.
Barium oxide (BaO)	.72
Magnesium oxide (MgO)	.23
Potassium oxide (K_2O)	.47
Sodium oxide (Na_2O)	.08
Lithium oxide (LiO)	(*a*)
Water below 110° C	.56
Water above 110° C	1.16
Sulphur trioxide (SO_3)	.44
Phosphorus pentoxide (P_2O_5)	.08
Antimony pentoxide (Sb_2O_5)	None.
Arsenic pentoxide (As_2O_5)	1.60
Arsenic disulphide (As_2S_2)	None.
Molybdenum (Mo)	(?)
Tellurium (Te)	(?)
Total	100.00

a Strong trace.

Except for the fact that the Silver ledge ore is characterized by the presence of considerable antimony and little arsenic, and the gold ore by considerable arsenic and no antimony, the foregoing analysis is very much like that of the silver ore from the Sparrowhawk, which has already been given (p. 394). It shows a considerable degree of difference from the analysis of the unoxidized ore from the Golden Gate. A large part of the difference between the two varieties of gold ore comes, of course, from the oxidation, but it is not fair to assume that the alteration is sufficient to account for all of the changes. In the case of the ore from the Mercur stopes the rock is evidently an altered limestone, while that from the Golden Gate is an altered porphyry, and these original differences show very clearly through the effects of the mineralization.

On the other hand, the gold ore of the Apex stopes and the silver ore from the Sparrowhawk are both the result of the alteration of similar limestones, and hence the general similarity of their chemical composition. It is in the differing nature of the rarer metals which they contain, and which are most closely connected with the mineralization, that the difference in the character of the ores and of the mineralizing processes is indicated. In the same way, the relation between the Golden Gate and the Mercur ores is not indicated by the general analysis, but by the presence of the same rare element in both, viz, abundant arsenic, and by the entire absence of antimony.

Judging from the physical characters of the ores, their relationship as above indicated is not to be mistaken. The ores are divided by every miner at first sight into two classes which do not resemble each other, those containing silver and those containing gold. There is only one class of silver ore, for the oxidizable materials are not abundant enough to make any material change in the appearance of the ore when weathered. The ore remains massive and siliceous, with dark-gray color, typically brecciated appearance, and ramifying veins of calcite and barite. On the other hand, the gold ores are friable and even pulverulent, for the grains are not firmly compacted in the unoxidized state, and become almost entirely incoherent on weathering. The color and consistency have procured for the latter the popular name of shale, which in many cases they strongly resemble. On oxidation this color quickly disappears, and is replaced by a light tint, usually pearl-gray or cream-yellow, and there arises a striking but irregular banding, sometimes horizontal, but usually curved and often concentric, from the concentration of the iron of the oxidized pyrite along lines of greater weakness than the rest of the rock. (See figs. 42 and 47, pp. 407, 444.) But in both the oxidized and the sulphide ores the general characters are much the same, and the oxidation produces a change in constituents which make up only a small part of the rock rather than a complete change in its general nature.

IRON.

The analysis of the specimen of sulphide ore shows 6.60 per cent of pyrite and only 0.31 per cent of iron oxides, the latter being probably due to the incipient oxidation of the pyrite. In the analysis of the oxidized ore we find that the pyrite has entirely disappeared, and the rock contains only 2.07 per cent of the iron oxides. Allowing for the difference in the weight caused by the substitution of oxygen for the heavier sulphur in combination with the iron, there still remains in the weathered ore less than half the quantity of iron which exists in unoxidized form. If we assume that before the oxidation both ores had approximately the same amount of iron, it follows that a part has been removed in the process of oxidation. What remains is chiefly in the form of the sesquioxide, probably hydrous, and has segregated into the red and yellow bands which distinguish the oxidized ore. Most of the iron protoxide is probably in the form of iron sulphate, being combined with the sulphur trioxide recorded in the analysis. This salt is readily soluble, and being a common product of the oxidation of pyrite is undoubtedly the form in which much of the iron has been removed from the rock. That iron sulphate in solution is actually present in the rock is shown by the formation on the walls of drifts which cut the black sulphide ore of large quantities of the fine, colorless, astringent-tasting crystals of melanterite, which is crystallized iron sulphate. This mineral is very common, being especially noted in one of the Protective Tariff tunnels and in one of the smaller tunnels of the Mercur mine.

ARSENIC.

In the unoxidized ore arsenic is mainly in the form of the sulphide, realgar, and, as in the case of the iron, that portion which is in the form of oxide undoubtedly represents the product of incipient decomposition. In the oxidized ore the sulphide has totally disappeared, but most of the arsenic remains in the form of pentoxide. It is probable that a large part of this pentoxide is in combination with other elements, chiefly iron. A characteristic of the oxidized ores is a light-green stain or thin film, which is found in all the crevices of the rock and which gives the green color to many of the segregated bands. Some of this mineral was examined chemically and found to be a hydrous ferric arsenate, probably scorodite. A large part of the arsenic pentoxide in the rock may be combined in the form of this and similar minerals, and in this combination may be included a part of the iron derived from the oxidization of the pyrites. Since these arsenates are readily soluble under certain conditions, they are found distributed pretty generally throughout the ores, and even leached down into the rock beneath.

MERCURY.

The amount of mercury in the ores is probably not so great as one at first might suppose. In neither of the specimens of gold ore was it possible to find any positive trace of the metal, although special tests were made. This is rather remarkable, for the sample of oxidized ore was taken from the Apex stopes at a locality where specimens of the bright-red, earthy cinnabar are frequent. The fact that there was none in the specimen analyzed shows that the metal is probably sporadically concentrated in these oxidized ores. If, then, the rock which does not show cinnabar to the naked eye is barren of the mineral, the small concentrations which are frequently encountered will amount to a very small percentage of the whole rock. In the early days, when the district figured as a silver producer and when what is now mined for gold was exploited for mercury, it was claimed that the ore in some places averaged 4 per cent, but this seems to be very improbable.

In the sulphide ores no cinnabar can ordinarily be found. Mr. R. C. Hills mentions finding it in the Golden Gate mine "only in very small specks, scarcely noticeable without a lens." The presence of a large amount of mercury in the Golden Gate ore is reported from sundry sources, but these reports are not considered reliable by the owners. It is probable that the metal exists in the sulphide ores in small quantity, finely disseminated throughout, but what its form is is not definitely known. The small specks of earthy cinnabar, as well as the larger quantity in the oxidized ores, are probably the result of the alteration of some other form. It seems certain that it has undergone some change, for it is a mineral highly susceptible to varying conditions and could not remain unaltered during the oxidation of the arsenic and the iron.

Around many of the small rounded pellets of cinnabar in the oxidized ores is a small amount of a grayish-black mineral with metallic luster. In most cases the relation of the cinnabar to the black mineral is such as to suggest that the cinnabar is the older of the two, from which the other has been derived; but occasionally, especially in small grains seen by incident light under the microscope, it seems possible that the reverse is the case. In some places the black mineral forms the larger part of a small pellet, with only a little cinnabar in the center; but more often it appears to form a very slight crust on the outside of the cinnabar. It is never so abundant as to be conspicuous in the hand specimen, being well observed only with the aid of a magnifying glass. Enough of this mineral could not be obtained for analysis, but tests show that it is not metacinnabarite, the black sulphide of mercury, as its association at first suggested. Tests for selenium were also made, it being suspected that the mineral might be tiemannite or some other selenide, but without result. In thin sections of the unaltered sulphide ores of the Golden Gate mine small irregular grains of what appeared to be the same mineral were observed, so situated as to seem to have crystallized at the same time as the realgar. It is possible that this is the original form of all the mercury.

GOLD.

That some change in the nature of the gold is brought about by oxidation is shown by the difference in the behavior of the sulphide and the oxidized ores. In the latter the gold is readily soluble in potassium cyanide, and is thus extracted, while in the former it is only slightly soluble. In neither the sulphide nor the oxidized ore has the form of the gold been determined. It exists in both in a very finely divided condition, for particles are never large enough to be detected by the naked eye, or, up to this time, by the microscope. From the solubility of the gold in the oxidized ores in potassium cyanide, it has been supposed to be in the free state, for the power of this cyanide to dissolve the finely divided metal is well known. Judging by the same criterion, the gold in the sulphide ores is not in the state of the simple metal—at least, such as we know it. It also appears that the gold is not especially associated with any of the sulphides which accompany it, and therefore the theory that it may be in the native condition, but protected from the action of solvents by the inclosing minerals, is not probable.

The fact that in the sulphide ore gold is no more abundant in the realgar than in the rest of the material has been shown by comparative assaying. Mr. R. C. Hills[1] states that samples of Mercur ore rich in

[1] Ore deposits of Camp Floyd district, p. 9.

realgar often prove on assay to contain little more than traces of gold; and he also records that Dr. Richard Pearce "carefully separated some of the realgar from a sample of Golden Gate ore, the former affording only a trace of gold, though a previous assay of the ore itself had demonstrated its fair average value." Mr. R. H. Officer and Mr. J. W. Neill, of Salt Lake City, have made the following experiments for the purpose of determining this fact. A selected piece of ore from the Golden Gate mine, which was mainly solid realgar, was assayed and found to contain 0.07 ounce of gold to the ton. Next, a portion of the same specimen was roasted and the arsenic completely driven off. The nonvolatile residue constituted 16 per cent of the original specimen. It was siliceous in nature and light-gray in color. This residue proved on assay to contain 0.35 ounce of gold to the ton. Similar results were reached in assays made especially for the Survey. A sample of Golden Gate ore which was selected as being particularly rich in arsenic, containing probably 50 to 75 per cent of realgar, was found to contain gold in the ratio of 0.42 ounce to the ton. This is not above the probable average of all the ores of the Golden Gate. Subsequently a similar specimen was ground, and by means of sieves those grains having a diameter of between one-fortieth and one-sixtieth of an inch were separated from the rest. These were then put into a Thoulet solution having a specific gravity of 2.85. That which sank appeared under the hand lens to be nearly pure realgar, and was assayed, giving a result of 0.50 ounce to the ton of ore. All these experiments show that, although in a general way the presence of arsenic in the unoxidized ores is a favorable sign for the existence of gold, as being an indicator of the mineralization which introduced both elements, yet the two are not always closely associated in the deposits.

Neither has there been found any close association between the cinnabar and the gold. The same general relation which has been described for the realgar holds good for the cinnabar, and this relation appears to be closer than in the case of the former mineral, for those portions of the ore which contain cinnabar are almost invariably of good value, and often are especially rich. But attempts to discover an intimate connection between gold and mercury have been unsuccessful. Mr. R. C. Hills mentions that assays of selected samples containing a high percentage of cinnabar "gave only from \$5 to \$6 per ton in gold, indicating that only a small portion of the metal in the ore was contained in that mineral."[1] Likewise, a specimen taken from portions of the Mercur ore especially rich in cinnabar was examined in the laboratory of the Survey, and found to contain gold in the proportion of 0.40 ounce to the ton, worth about \$8.

Messrs. Officer and Neill have made the following experiments to determine the significance of pyrite in the sulphide ores: First, a sample of black shale containing pyrite was taken from the lower and

[1] Ore deposits of Camp Floyd district, supra cit.

lesser water-bearing zone which is cut in the Surprise shaft. This fossiliferous and truly sedimentary shale never contains more than a trace of gold, so far as observation has gone, and is thus to be distinguished from the so-called "black shale," which is really altered limestone and porphyry. The latter is also pyritiferous and is characteristic of the ore horizon. The pyrite concentrated from the sample of water-bearing shale gave only a trace of gold on assaying. Second, from a sample of Golden Gate ore which assayed $11 (0.55 ounce) to the ton, the pyrite was concentrated by panning. That panned out was about 1 per cent of the total weight of the ore, and assayed $44 (2.20 ounces) to the ton.

The results of this last experiment are not convincing in either direction. On the one hand, the pyrite which was panned out of the rock was found to have a content of gold four times as large as that of the rock in general. On the other hand, it formed a very small part of the total weight of the rock, and so contained a very small proportion of its value. In a ton of the ore, for example, there would be $11 worth of gold, while in the 1 per cent of pyrite contained therein there would be $0.44 worth, and the balance, or $10.56 worth, is in the residue. If, therefore, all or even a large part of the whole amount of pyrite was removed from the ore in this experiment, it indicates that the gold, although owing to chemical relations it has an affinity for iron, was originally deposited and still continues mainly independent of it.

Mr. Hills in his paper suggests the possibility that the gold occurs in combination with tellurium. Owing to the small quantity of gold, which averages hardly over half an ounce in the ton of ore, and is never known by the writer to have exceeded 3 ounces, chemical investigation on this subject has been unsatisfactory, no gold having been detected by wet analysis. If the gold is in the state of telluride, therefore, it is only by concentration and elaborate analyses that this can be fully proved. But the analyses already given show that tellurium does exist in the Mercur ores. Curiously, however, the most pronounced trace was found in the silver ore of the Sparrowhawk mine, where both tellurium and molybdenum are present, probably in the fully oxidized state. There is a very small amount of gold in the Sparrowhawk ores, one assay showing 0.035 ounce to the ton, and another a trace, but the amount is probably not sufficient to account for the presence of tellurium in the analysis. It may then be assumed either that the tellurium was originally present in the Silver ledge in other forms than in combination with gold, or that, on the decomposition of gold tellurides in the gold ore above, the freed tellurous acid, which is readily soluble in alkaline waters, was leached down into the silver ores below. This is the origin that has been suggested for the oxidized arsenic in the silver ores of the same mine.

In the sulphide ore from the Golden Gate mine no molybdenum was found, but a probable trace of tellurium. No test for tellurium was made of the oxidized ores, but they probably contain small quantities of tellurium in the fully oxidized state. Even a trace of tellurium in so small an amount of ore as must necessarily be taken for analysis is sufficient to unite with the gold, which also occurs in very small quantities. The insolubility of the sulphide ore in the cyanide solution and the solubility in the same of the oxidized ore is consistent with this idea. Telluride of gold is not readily attacked by the cyanide, but on oxidation breaks up, forming native gold and tellurous acid, and the gold can then be dissolved in the solution. Results similar to this are obtained by roasting the sulphide ore of the Golden Gate. Messrs. Neill and Officer found that, after roasting, about 63 per cent of the gold could be leached out by cyanide; in roasting, however, there was a loss of gold varying up to 13 per cent. This constant loss in roasting is significant as to the probable form of the gold, for such loss is usually much greater in the tellurides than in other ores.

While, therefore, it is as yet not proved in what condition the gold may be, the evidence is most favorable toward the hypothesis that it is in its original form a telluride, very finely disseminated; and that, on oxidation by natural processes or by roasting, it becomes free gold.

CONDITION OF THE GOLD IN THE OXIDIZED ORES.

It seems most probable that the gold exists in the oxidized ores in the free state, but in a very finely divided condition, and probably in a form somewhat different from that of ordinary metallic gold. The gold obtained by precipitation from solution is a fine powder, black, brown, purple, or red in color, without metallic luster. This amorphous gold offers various points of difference from the yellow, ordinary variety, which have been summed up by Mr. Henry Louis in a paper read before the American Institute of Mining Engineers.[1] Thomsen had shown that the behavior of amorphous gold when acted upon by chlorine or bromine is different from that of ordinary gold; in the first instance aurylic compounds (Au_2Cl_4 or Au_2Br_4), and in the second auric salts ($AuCl_3$ or $AuBr_3$) are produced. Mr. Louis states that the two varieties have also a different density, although there is every stage of gradation between the two extremes. Another point of difference brought out by his investigations is in their behavior toward mercury. The readiness of the common form of gold to form an amalgam with mercury is one of the best-known properties of the metal, since it is so extensively used in the treatment of ores. But gold precipitated from highly dilute solutions by means of ferrous sulphate is not at all attacked by mercury when freshly precipitated, and only slightly when dried. While indifferent to mercury, this gold is in a form in which it is readily attacked by chlorine and potassic cyanide. Mr. Louis makes the following provisional deductions from his investigations:

"1. Gold is capable of existing in allotropic modifications.

---

[1] The Allotropism of Gold, Trans. Am. Inst. Min. Eng. Vol. XXIV, 1894, p. 182.

"2. One of these modifications is capable of amalgamation with great difficulty, if at all.

"3. This modification is capable of being produced and of subsisting under conditions which may be reasonably supposed to exist in nature when gold is deposited in reefs."

In the Mercur oxidized ore the gold has the same peculiarities as are here indicated for the supposed allotropic form. As already stated, all attempts to extract it by amalgamation have proved failures, only a very small portion of the metal being concentrated by this means, while the results of treatment with the solution of cyanide of potassium are very satisfactory. As a purely theoretical reason it may be added that if, as suggested below, the gold has been affected during the process of oxidation, having been taken into solution by alkaline waters and precipitated by the ferrous sulphate derived from the oxidation of the pyrite, it would then be in the amorphous form which is indifferent to mercury, as shown by the laboratory experiments mentioned above.

FORMATION OF SULPHATES.

The oxidation of the iron pyrites has resulted in large part in the formation of hydrous ferrous sulphate, which crystallizes out in considerable quantity on the walls of newly opened drifts in ore not entirely oxidized. This mineral, melanterite, occurs in many fine, colorless prisms, which dissolve readily in the mouth, leaving a peculiar astringent taste. On account of its ready solubility it is not permanent, and is therefore not found in portions of the ore which have been completely oxidized.

The conversion of calcite to gypsum is another of the results effected by soluble sulphates resulting from the oxidation of the sulphides. The detailed evidence of this transformation has been given in the description of the Mercur mine. It is in certain regions where circulation is the freest, such as the preexisting vertical fissures and sheeted zones, that this change has chiefly gone on. On such a zone a vein of gypsum is often found in softened and altered limestone, which becomes transformed into a vein of calcite on entering the hard and unchanged rock.

NATIVE SULPHUR.

In the Mercur district as mapped no native sulphur has been found. According to Mr. A. H. Holden, of Salt Lake City, it is found in the oxidized portions of the Sunshine mines, which lie a few miles to the south of Mercur. These mines are on the contact with the same general sheet of porphyry as at Mercur, and undoubtedly have a similar origin. The production of sulphur is probably due to the reduction of sulphides with scanty access of oxygen; freer access of oxygen produces sulphuric acid and the sulphates.

CONCENTRATION OF THE GOLD.

The gold in the oxidized ore seems to be somewhat concentrated, so as to be richer in some places than the average sulphide ore and poorer in others. This concentration does not appear to be important. The ferrous sulphate derived from the decomposing pyrite may have had some part in the process, for this salt is a very effective precipitant of gold in solution.

It has already been noted that the ore on oxidation becomes less coherent. This change is undoubtedly caused by a decrease in bulk, due to the leaching out of the more soluble portions. The chief part remaining is the insoluble silica.

LOCUS OF MINERALIZATION.

CONTACT OF PORPHYRY AND LIMESTONE.

The locus of greatest mineralization in the gold ores is primarily at the lower contact of the thin sheet of porphyry next above the lowest, or Silver-ledge sheet, with the blue limestone. From the contact the mineralization extends downward into the limestone for a few feet without great change, and then falls off rapidly, so that the ore gives place irregularly to unaltered and barren limestone, which, however, nearly always carries a trace of gold. According to the local intensity of the alteration the width of the zone which has been mineralized sufficiently to be available as ore varies from 2 or 3 to 25 or 30 feet, and as a rule the ore is richest where the quantity is greatest.

Above the contact, alteration and mineralization of the porphyry take place very slowly. This rock is always a good deal decomposed, and is often in a partly pulverulent condition. If the country were not so dry much of it would form stiff clays like those which are so common in the mines at Leadville. This altered porphyry always contains a trace of gold, but is generally not rich enough to be classed as an ore. Where the alteration has been least, and the mineralized zone of limestone is narrowest, the ore stops abruptly at the contact with the porphyry, so that the roofs of the stopes are usually smooth and uniform. Where the mineralization has been greater the lower part of the porphyry may be sufficiently impregnated to be mined along with the richer ores below; but it is always of distinctly lower grade than the altered limestone. Occasionally the whole porphyry sheet, where it is not very thick, may be sufficiently mineralized to form a low-grade ore. Above the porphyry, in localities where the mineralization has been especially great, the limestone is sometimes altered for a short distance, the softened portions extending irregularly upward into the hard rock. The writer has not seen any place, however, where the limestone above the porphyry was mined as ore.

JOINT PLANES.

The limestone which constitutes the ore is not always, perhaps not usually, greatly altered. Much of it is fresh and hard, while the softer altered rock occupies limited areas. The mineralization follows the same channels here as the alteration, being greatest along whatever cracks or lines of weakness may be present. There are no systems of intersecting joints in the rocks, such as might be supposed to result from regional stress. The northeast vertical fractures are not like ordinary joints, since they are variable in their distribution, sometimes being absent and sometimes forming intensely sheeted zones. But on the beginning of alteration the slight shrinkage causes certain planes of weakness to develop, chiefly a horizontal plane more or less exactly parallel to the stratification, and vertical planes having various trends, so that the rock is divided into blocks, from whose periphery the mineralization penetrates inward. In some of the ore, so small is the amount thus considerably affected that only the corners and edges of the blocks are rounded, and much the larger part of the ore is comparatively barren limestone. The pulverulent matter in the crevices is generally of a greenish tinge, resulting from the presence of oxidized arsenic compounds; this carries most of the values. A couple of assays were made to prove this. Both were from the same locality, a short tunnel just south of the United States Mineral Monument, on the top of Marion Hill. Here the limestone below the contact with the altered porphyry is mainly of the fresh, hard variety, and is separated into blocks, often slightly rounded by decomposition. From the outside of several of these blocks the greenish, decomposed material was scraped, all harder rock being excluded. This assayed in gold 0.125 ounce to the ton and nothing in silver. Then the same blocks were broken open, and the hard, sometimes cherty limestone was taken, to the exclusion of the softer parts. This assayed a trace in gold and 0.38 ounce in silver.

VERTICAL FISSURES.

The vertical fissures, which form one of the most conspicuous features in the mines, have undoubtedly been instrumental in opening the rocks through which they pass to the mineralizing currents. They are generally northeast in trend, varying considerably, but still ordinarily keeping near the average of N. 20° E.; they are generally vertical, with sometimes a very steep dip to the northwest, the angle of which is rarely less than 80°. Sometimes the notable fractures are a little distance apart and are separated by massive limestone; sometimes they are crowded close together and form a sheeted zone. Along such zones the pulverized rock crumbles readily, and is easily carried away, leaving the open fissures which have been described. In the ore bed, owing to the alteration, the fractures are ordinarily lost sight of, but they appear in the hard limestone above and below.

Two cases in the Mercur mine have been described where such a sheeted zone has determined an irregularity in the ore body, in the shape of a vertical tongue of altered and mineralized limestone, extending downward from the main ore sheet. These vertical zones of ore have walls of hard limestone on both sides. They are ordinarily exposed only for the height of the tunnels by which they are cut, and no data as to their downward extension can be obtained. In one case, however, that near the end of the main Nimrod tunnel, in the Mercur mine, an upraise has followed the vein for a distance of 50 feet or more, but the rock at the top was reported as growing harder and as very little mineralized. The drift which follows the same vein laterally shows the mineralization to become less and finally almost to disappear. Commercially, therefore, it is unlikely that any of these vertical zones of mineralization will become important; it is not probable that they extend downward for any great distance, or are persistent in any direction. On the other hand, the presence of these smaller ore zones is a proof of the possibility that bodies of similar nature may become large and persistent enough to be of value, and this fact should be kept in view in mining.

The fact, however, that the mineralization has proceeded more actively along these fissures and sheeted zones than in the rest of the rock is one of considerable importance. The walls of many open fractures carry crusts of arsenic sulphide, the form in which the arsenic of all the ores was originally deposited. This arsenic extends downward farther into the rock than do the mercury and the gold, and characteristically follows the vertical sheeted zones. Its presence as a sulphide shows that the alteration along these zones has not been due to an action secondary to the mineralization of the chief ore sheet above, by which the mineral elements were leached downward into the rocks below, but was brought about at the time of the original mineralization.

Other facts indicate the general tendency of the ore to run parallel with these fractures. In the mines where ore has been taken out in any large quantity the thicker and richer portions show a constant tendency to run in a northeast direction, in the manner of northeast parallel ridges on the under surface of the sheet. The great ore body which is exposed in the workings of the Mercur mine, and of which enough has been taken out to show its shape, is several times as long as it is wide, and its longer axis runs northeast. Furthermore, if a line be drawn from the middle of the Mercur mine through the Golden Gate ore body, it will have a direction of about N. 22° E., and if this line is extended southwest it runs close to the Mattie No. 5, where a small find of ore has been claimed, and through the Sacramento tunnel, where there has been considerable mineralization, but from which no ore has as yet been shipped. A parallel line drawn from the top of Marion Hill would pass close to the Marion and the Geyser, from the former of which a large quantity of ore has been shipped; and to the Protective Tariff and Brickyard tunnels, which show many of the characteristic features of the Gold ledge mineralization, but have not become ore producers. A belt 1,000 feet wide in its widest parts, following each of the two lines described, would include all of the localities where the assays made by the Survey indicate that gold is present in quantity exceeding one-tenth of an ounce to the ton. These localities, in the belt drawn through the Mercur, comprise the Sacramento tunnel, the Mercur, and the Golden Gate; the zone drawn through the Marion would include the Marion, the Geyser, the Protective Tariff, and the Brickyard.

CONCLUSION.

The existence of a body of gold ore in the Mercur district is believed to depend on the following conditions:

1. It must be at and just below the under contact of a sheet of porphyry with limestone, and this contact must be one that has not suffered profound Silver ledge mineralization. Thin sheets are most favorable, for they have been most thoroughly decomposed, and this decomposition seems to have been favorable to the mineralization. Since the lowest thin sheet has been mainly rendered proof against further alteration by the effects of the Silver ledge silicification, it is on the contact of the sheet next above that all the valuable ore bodies have thus far been discovered. While other bodies may be found on other contacts, it is along this sheet that the most ore will probably be found in the future, as it has been in the past.

2. The ore is by no means distributed all over this contact, but only along certain sheeted zones, which are characterized by narrow, straight, open fractures. These zones are nearly vertical and have a general northeast trend, and where they intersect the lower contact of porphyry and limestone above described the ore bodies may be formed.

3. While the mineralization is characteristically greater along the whole extent of these zones than in the rest of the rock, it is only in certain portions that it becomes great enough to form an ore. The ore bodies, therefore, have probably in general a long northeast, with a considerably shorter northwest, axis, while the vertical dimension is comparatively small, rarely exceeding 30 feet.

AGE OF MINERALIZATION.

There is evidence that the mineralization of the gold ores occurred at a period later than the mineralization of the Silver ledge and the formation of the calcite veins which are so abundant in all the rocks. Some of the smaller of these veins may have been deposited later than the rest, contemporaneously with or even subsequently to the period of mineralization in the gold horizon, as various rather rare phenomena indicate; but nearly all were probably formed in the closing stages of the mineralization of the Silver ledge, or very soon after.

AGE OF VERTICAL FISSURES.

It has been shown that the vertical fissures existed before the advent of the gold, and were apparently the chief channels for this mineralization. That these fissures were formed after the mineralization of the Silver ledge is indicated in various ways. In many places in the mine workings they are seen cutting the older calcite veins, whose age is very nearly or quite that of the Silver ledge. On the side of Marion Hill and in Marion Gulch are many slight faults with a general northeast trend; near the mouth of the gulch most of the fault fractures have been completely healed by crystalline calcite. These, therefore, appear to belong to the older fracture system, corresponding to the calcite veins in the Silver ledge. On the hillside, however, are parallel fissures of the later open type, which cut the calcite veins. Along these later fractures, too, there has been some faulting, as one or two exposed sections show. In one place (see fig. 46) there is exposed a vertical sheeted and brecciated zone, over a foot wide and trending N. 40° E; the brecciated material is somewhat decomposed and loose, there being no

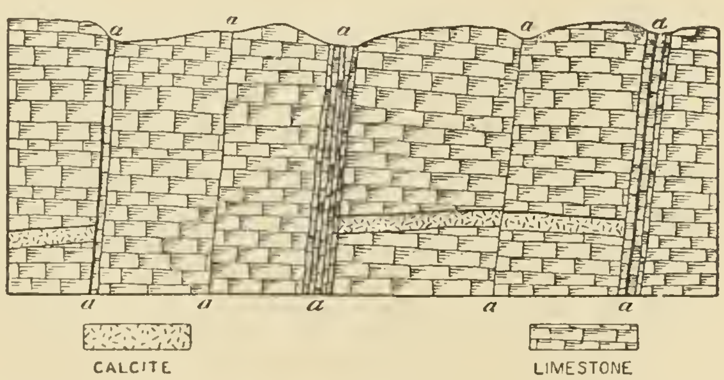


FIG. 46.—Open fissures in cliff on Marion Hill. *a*, *a*, unfilled fissures.

cement between the fragments. On the northwest side of the fractured zone there are many calcite veins in the hard limestone, mainly parallel with the stratification. One is nearly a foot wide. On the southeast side, however, there is not a single vein. The breccia contains many fragments of calcite, derived from the veins on the northwest side, showing that there has been some faulting accompanying the fracturing. As in most of the smaller faults in this vicinity, the upthrow is to the northwest, here about 20 feet.

In the Silver ledge proper the phenomena point to the same conclusions. The silicified and mineralized rock is traversed by large, vertical, open fractures, which have been described in the Silver Cloud workings and elsewhere. These fractures cut through the calcite veins and geodes and the altered limestone; their walls are generally bare, with only scanty beginnings of healing by calcite. In the case of the Marion gold mine and the old Carrie Steele silver mine, one of which is almost directly above the other, the same set of fissures run through both. In the gold ores above they are not usually characterized by open spaces, but by slight faults, along which the ore has formed in such a way as to indicate that the mineralization has been subsequent to the fracturing. When these same fractures are encountered in the Silver ledge below, they are open, with hard bare walls, as if the fracturing were recent. The ore does not follow along these courses, and apparently has no connection with them. These facts all go to show that the mineralization of the gold horizon took place at a time distinctly subsequent to the formation of the silver ores.

EVIDENCE OF PRIMARY MINERALIZATION IN THE GOLD HORIZON.

Since the mineralization of the Silver ledge preceded that of the gold ores, we might expect to find, in places, traces of the primary mineralization on the horizon of the gold ores, for, according to the theory of the formation of the Silver ledge, the gold-ore horizon is one where some such action should have taken place, although in much less degree than along the sheet below. As a matter of fact, frequent phenomena were observed which apparently should be referred to this earlier mineralization. The cherty portion of the ore in the Gold ledge, where it has been least broken up and decomposed, is exactly like the characteristic rock of the Silver ledge. It will be remembered that this broken and cherty zone occurs, in the mine workings, always directly beneath the altered porphyry, and never extends far downward, nor is it found at a lower horizon. Where the limestone has been altered to ore below this zone, as it very commonly is, or where the chert is lacking, the rock is softened and becomes more friable; and since this softening is characteristic of the gold ores, it is evident that the hardening or silicification could not have been brought about by the same forces. Other things show that the chert was present before the introduction of the gold. One is its presence in brecciated condition in the ore, with loose, disintegrated material between, which contains most of the gold. This indicates a movement since the formation of the chert and before the mineralization, and this movement was undoubtedly contemporaneous with the vertical fracturing.

Another evidence that the chert was present prior to the mineralization is that it contains scarcely any gold, hardly more than a trace, even when occurring in the midst of the gold ores. This fact has been verified by various assays made by Mr. Hills.[1] In this connection an experiment previously described on ores on Marion Hill should be recalled. The ore under consideration is chiefly in hard, sometimes cherty limestone, which is separated into blocks by narrow zones of decomposed and pulverulent material. This lies under a belt of broken chert which in turn is below altered porphyry. From the outside of the blocks of hard limestone the greenish, pulverulent stuff was scraped, excluding the harder portions. This assayed nothing in silver, but in gold 0.125 ounce to the ton. Then from the same blocks a sample

---

[1] Op. cit., p. 9.

consisting only of the hard unaltered material was taken, which gave 0.38 ounce in silver and only a trace of gold. Since even traces of silver are practically absent in the gold ores, we must admit that the silver found in the hard limestone in the second assay must have been introduced by some earlier mineralization. The scarcity of silver in the chert at other localities in the gold ore is rather singular, but is undoubtedly to be explained by the ready solubility of the silver chloride. Where the rock has, as in these places, been profoundly fractured and exposed to the altering agents of the second mineralizing period, as well as to subsequent oxidizing forces, it is no great wonder that all of the silver has ordinarily been leached out.

Several other phenomena distinctly characteristic of the Silver ledge accompany the chert in the gold ores. One is the occurrence of the mineral Chinese talc, or impure jarosite. This is probably the product of the alteration of porphyry by waters containing soluble sulphates, which may have been derived from the oxidation of original sulphides. Such alteration may have had, therefore, no necessary connection with any distinct period of mineralization. In the case of the Silver ledge, indeed, it is believed to have formed at a period somewhat later than the mineralization, along with the alteration of the porphyry. In the case of the gold ores, however, the evidence goes to show that the decomposition was mainly accomplished before the characteristic mineralization took place, so that the formation of the Chinese talc was also probably prior to this mineralization. Since it is in its nature, habit, and association indistinguishable from the Chinese talc of the Silver ledge, a similar and in a general way contemporaneous origin may be supposed for both.

Barite has been observed in the gold ores only in the cherty rock, which is supposed to be due to the primary mineralization. In portions of the ore which are only softened limestone, with very little or no cherty material, it does not appear. In the chert the formation of the barite veins at the time of the primary mineralization is indicated by various phenomena. The habit of the veins is identical with that of the Silver ledge barite, since they are not characteristically persistent, but ramify in all directions, or penetrate the rock in a confused and intricate manner which can hardly be described or figured. As in the Silver ledge, the general tendency of the veins is rather to be parallel to the stratification of the limestone than otherwise, although some are vertical. In the Silver ledge, moreover, the barite is generally fresh, whereas in most places in the gold ore it is considerably decomposed, so that it crumbles readily on touching. Since this alteration is shared by the chert and altered limestone near it, it must have taken place before or at the time of the gold mineralization. The only change of importance which appears to have occurred since this is the oxidation, which is not capable of having produced all this decomposition. It follows from this that the barite was probably in the rocks at a time previous to the secondary mineralization, and from its resemblance to the barite, which is known to have been formed at the time of the primary mineralization, as well as from its association, it may be supposed to have originated at the same time as the silver ores.

To determine as nearly as possible what was the relative content of gold originally present in the barite, a set of assays were made from material obtained in the Mercur tunnel, about 150 feet from the mouth. Here the veins are very large, some of them being nearly a foot wide in places. For this reason portions are comparatively fresh, while that on the outside of the veins is decomposed. There are left in the veins many cavities, into which the crystals of barite project, and from the barite forming the walls of these cavities the first sample was taken. This assayed 0.16 ounce in gold to the ton. Next, the freshest barite that could be obtained was taken, showing only traces of disintegration, and adjacent neither to the walls of the vein nor to the cavities. This assayed 0.025 ounce in gold. Next, a sample was taken from the altered limestone adjacent to the veins, from which all barite was excluded. This assayed 1.02 ounce in gold. At a little distance from the place where these three samples were taken the limestone contains small ramifying veins of barite. Both lime and barite are crumbling, and carry cinnabar. A sample of this barite was taken, from which, however, the pulverulent altered lime could not well be separated; indeed, it is probable that it formed the larger part. This assayed 2.42 ounces in gold. The result of these assays shows that the barite in its freshest condition in the gold ores carries only traces of the metal, thus furnishing a further point of resemblance to the barite of the Silver ledge; but where it has become decomposed and crumbling, as in small veins or on the outside of large ones, it has been mineralized with the limestone. The amount of mineralization, however, seems to be somewhat less in the barite than in the limestone.

PRIMARY AND SECONDARY MINERALIZATION IN THE SAME LOCALITY.

The characteristics of the Silver ledge on the southwest side of Mercur Hill have been already described (see p. 383). Here the silicified zone, which is about 10 or 15 feet thick, forms a prominent outcrop by reason of its hardness. Below this the limestone is hard and blue, showing no alteration even under the microscope, but appearing as a pure, uncrystallized limestone, apparently little different, except for consolidation, from the slimy form in which it was originally deposited. Above the Silver ledge comes from 15 to 25 feet of porphyry, considerably altered, although still quite hard in some places. Above the porphyry comes the blue limestone again, slightly hardened and crystallized along the contact, but not approaching the usual alteration of the Silver ledge. In the locality where the open cuts are the largest the porphyry is more decomposed than usual, being shrunken and traversed by curved and often concentric brown and yellow bands. It is thus in the exact condition of the altered porphyry roof described in the gold mines. The Silver ledge below this is of typical appearance, although it shows a tendency to crumble at the top, and thus forms a somewhat gradual transition. At the exact contact the condition is identical with that of the broken and cherty parts of the gold ores in the Mercur mine. The primary mineralization seems to have been considerable here, for the silicification is very complete, barite veins are abundant, and the larger open cuts indicate a greater extraction of silver ore than anywhere else in the immediate vicinity.

From the altered porphyry samples were taken for assay. One test showed a content of gold in the ratio of 0.03 ounce to the ton, no trial being made for silver; another gave 0.018 ounce of gold and 0.6 ounce of silver. Although these amounts of gold are very small, yet they are as much as is often given by the altered porphyry roof in the mines, even in the ore bodies. In this case, however, the limestone below the porphyry, which at the main gold horizon forms the ore, was entirely silicified and mineralized at the time of the primary mineralization, and so was rendered insusceptible to much further change. Here, therefore, is a place where the two processes of mineralization have successively acted. The horizon, being that of the lowest porphyry sheet, is that usually characterized by the effects of the primary mineralization. In this case, however, the mineralization was not intense enough to harden the upper part of the porphyry above, which therefore softened and decomposed. Becoming thus a less permeable layer, it offered a local resistance to the ascending mineralizing agents of the later period, and hence was slightly impregnated with gold.

Near the Brickyard tunnel a rock analogous to the Silver ledge also shows evidence of the later mineralization. This is not the typical Silver ledge rock, for it is only slightly silicified; its position on the contact of the Gold ledge porphyry accounts for this. It is about 3 feet thick, and is like those portions of the Silver ledge along the contact of the lower sheet where the alteration has been slight. This rock gave no silver on assay, but 0.12 ounce in gold.

These facts suggest a modification of the general idea of the distinctness of the Gold and Silver ledges, which should be noted. While in general this distinctness holds true, it is possible that there may be places where ore will be found carrying a considerable quantity of both silver and gold; and bodies of gold ore may have been formed in places on the lower contact of the lowest porphyry sheet.

NATURE OF MINERALIZATION.

ALTERATION OF GOLD LEDGE PORPHYRY.

Although much if not most of the alteration which both the porphyry and the limestone of the gold horizon have undergone was probably accomplished prior to the period of the later mineralization, yet it connects itself with this process when the causes of the mineralization are considered; for doubtless the altered condition of the rocks exercised a selective influence on the deposition of the ores.

A specimen of fresh porphyry from the vicinity of Eagle Hill shows under the microscope a finely microcrystalline ground-mass, in places made up of very small spherulites, which occasionally grade into a micropegmatitic intergrowth of quartz and feldspar. Lath-shaped microlites of feldspar are very common, but the main part of the ground-mass is not coarse enough to enable one to distinguish the component minerals. Phenocrysts are rare, but are fresh when found. They consist, so far as observed, of quartz, biotite, and orthoclase feldspar. The quartz is in crystals or irregular grains which show corrosion by the magma previous to the consolidation of the rock. The feldspar has crystal outlines, often rounded by corrosion, and shows no decomposition. The biotite is dark colored and strongly pleochroic. Along its cleavage cracks some of the iron has separated out as oxide.

Another specimen shows the beginnings of alteration. No change can be seen in the hand specimen, but under the microscope the ground-mass presents a yellowish tinge and a slight opacity in ordinary light. Around the edges of the spherulites, and in irregular patches throughout the ground-mass in general, there is an alteration which seems to result mainly in kaolin, while a less noticeable change produces occasional longitudinal flakes of muscovite. Next, the rock becomes finely porous, so that it adheres to the tongue; and it has a strong clayey odor. The phenocrysts are no longer distinguishable, and the iron of the biotite is gathered into scattered nodules of hydrous iron oxide, which gives to the hand specimen a brownish color. Often the oxide is concentrated into irregular wavy bands in the gray rock, such as are shown in fig. 47. The ground-mass is reduced to a very fine mixture, probably of silica and kaolin, which is sprinkled with muscovite. This is the typical state of the altered porphyries, both in the vicinity of the ore deposits and at a distance from them. At this stage the rock is generally soft and sometimes pulverulent. There seems to be a secondary action of a constructive nature, however, by which the grains of silica in the altered mass tend to grow continually larger, at the expense, apparently, of the kaolinic ingredients, and undoubtedly in part by the deposition of silica brought from outside by percolating waters. This process has generally had very small, although noticeable, effects in the porphyry of the gold ores; in that of the Silver ledge, however, where the silica is very abundant in the contiguous rocks, it appears to have caused in places a considerable transformation.

The evidence goes to show that the alteration of the Gold ledge porphyry was accomplished mainly after the deposition of the silver ores and before the deposition of the gold. The silver ores seem to have been deposited immediately after the intrusion of the porphyry, before any oxidizing agents could have had opportunity to act. The conditions under which they were deposited, moreover, were evidently such as to preclude the idea of the operation of such oxidizing agents as were evidently active in the alteration, until after the lapse of a considerable period of time. On the other hand, where there has been no mineralization the alteration is exactly like that in the gold ores, thus showing that the mineralizing agents had no important part in the process. Since this is the case, not only in the oxidized ores but in the sulphide ores as well, the alteration since the mineralization must also have been

FIG. 47.—Concentration banding in slightly altered porphyry. Natural size.

very insignificant, for the altering agents could not well have acted without affecting the sulphides, particularly that of arsenic, whereas in much of the rock microscopic study has shown that no oxidation has taken place. The structure of the ores, both in the field and under the microscope, points to the same conclusion—that the porphyry had very nearly reached its present state of decomposition before the minerals were deposited.

ALTERATION OF LIMESTONE.

The fresh limestone is exceedingly fine-grained, the individual grains being often so small as not to be distinguishable under the microscope. It is slightly darkened by the presence of organic matter, which gives it in the hand specimen its dark gray-blue color, but it is, notwithstanding, a very pure lime carbonate without dolomitization or any appreciable amount of silica. Scattered thickly throughout its mass are ordinarily many varied shapes of clearer and coarser calcite or aragonite, which are the sections of tiny marine fossils.

So far as observed, the process of alteration of the limestone seems to have been a gradual dissolution of the lime, with or without attendant replacement by cryptocrystalline silica. Sometimes this process has been entirely completed, so that the limestone is converted into a typical chert, dark-gray in color, and called "black quartz" by the miners. Microscopically it has the cherty structure, and is composed of silica varying from very finely cryptocrystalline to finely phenocrystalline, with often small but abundant cavities and veinlets partly or wholly filled with crystalline quartz. In other cases there remain in the chert small, irregular patches of calcite, which are probably residuary. Sometimes these patches are crystallized into rhombohedra. From a limestone partly replaced by silica the remaining calcite has very often been dissolved out. If silica has already replaced the greater part of the rock, there results from this leaching a very porous chert, full of small, irregular cavities; if the lime is still in excess, the silica is very often not in sufficient quantity to preserve the shape of the rock after its withdrawal. The rock therefore crumbles and becomes reduced to the light-gray pulverulent altered limestones of the oxidized gold ores and to the soft "black shale" of the sulphide ores, where the grains of quartz are to a certain extent cemented by the later minerals which accompanied the gold.

Most of the chert in the gold ores was probably formed before the introduction of the gold and the accompanying minerals, and probably at the time of the primary mineralization of the Silver ledge. This is shown by the similarity of this chert to that of the Silver ledge, and by the fact that it incloses some of the same most conspicuous minerals, such as barite and Chinese talc. The ores of the Gold ledge, moreover, were evidently not deposited at the same time as the chert, for where this chert is dense it contains only traces of gold; where it is porous the characteristic minerals of the later mineralization are found in its pores, and where the chert has been broken by a movement subsequent to its formation, the finer material between the larger fragments of the breccia has been chiefly impregnated.

REALGAR.

The most abundant and conspicuous mineral which has resulted from the later mineralization is the sulphide of arsenic. No one of the other minerals of the Gold ledge is present in such quantity and condition as to throw any light on the conditions of deposition. The gold itself has not been seen in the ores, even under the microscope; the form of the unaltered mercury in the sulphide ores has yet to be determined; pyrite is present in only small quantities, and the barite was probably in the rock before the later mineralization. But the sulphide of arsenic is nearly always distributed abundantly throughout the unaltered ores, and can be readily observed.

Under the microscope realgar is a very striking mineral, on account of its high single refraction and its rich reddish-brown color. It is translucent, and has a marked pleochroism, varying from golden-yellow, through greenish-yellow, to golden-brown. Under crossed nicols it shows a deep golden-brown. It alters on oxidation to a brilliant yellow mineral, which analyses show to be probably scorodite, a hydrous ferric arsenate. This is the greenish-yellow pulverulent mineral which is seen in hand specimens of all the oxidized ores.

In a section from a cherty portion of the ore in the Golden Gate mine the realgar occurs in irregular grains scattered through a mass of fine cryptocrystalline silica. The silica is very full of a very fine, dust-like, dark material, which gives the dark color to the rock. This material is arranged in imperfect lines or zones, forming a rude network; some of the larger bunches of this can be distinguished as very small, irregular grains of pyrite. There is a single large grain of barite, with ragged boundaries, but the barite and the realgar are not associated, and there is no evidence of their relative age. There are also sparsely disseminated, small grains of an opaque, grayish-black mineral, with dull metallic luster, which seems to have crystallized with the realgar. This resembles a mineral found in small quantities associated with the earthy cinnabar in the oxidized ores, of which enough could not be obtained for determination. It seems probable that it may be the original form of the mercury, since cinnabar is wanting in the sulphide ores except in very small specks, which are apparently the result of incipient oxidation. There is no crystalline quartz or calcite in the section, or other gangue for the realgar.

In another section of a Golden Gate ore very rich in realgar, which is not cherty but goes by the name of "black shale ore," the rock seems to be an altered porphyry, similar in every particular to the other altered porphyries near by. Much of the section is taken up by large grains of realgar, with irregular outlines. Realgar also forms a fine network through portions of the uncolored mass which represent the original rock. There is no gangue of silica, calcite, or barite.

CALCITE.

Throughout most of the ores calcite is entirely absent, and when present is in small quantities, which are probably residual from the limestone. In a few cases crystalline calcite is associated with the characteristic sulphides of the later mineralization, but this generally occurs outside of the body of the ores, and marks an inconspicuous process which is probably distinct from that which has formed the main part of the ores. Not even in a restricted sense can calcite be considered a gangue of the sulphides of the gold horizon.

BARITE.

Barite is found scattered through the gold ore in large veins, as already described, and also in small grains which are visible only under the microscope. These grains have usually irregular outlines, but often crystal boundaries. They may consist of a single individual, or may be an aggregate of minor grains. They are surrounded by chert and have the appearance of having crystallized at the same time with the silica. Whenever the minerals of the later mineralization are present there is apparently no close connection between them and the barite.

QUARTZ.

Megascopic and microscopic examination shows that crystalline quartz, like calcite, is generally absent from the gold ores. In only one of the sections examined was any quartz observed other than the fine-grained variety which makes up the chert, and which is evidently of an earlier origin than the mineralization. This section is from the side of an open fracture plane in the Marion mine, and shows numerous very small crystals of quartz surrounded by the chert of the completely silicified limestone, in which the outlines of fossils are still discernible. It is probable that in this case the crystals formed before the mineralization. In several sections from the similar ores of Sunshine, crystalline quartz was also found, generally in very small individuals, as above. In one section a very large crystal was found. This was much fractured and broken, with irregular corroded outlines. The arsenic sulphides penetrated the fractures and filled the spaces between the broken fragments, showing that they were undoubtedly introduced after the formation of the quartz. A single small megascopic crystal of quartz was found in the ores of the Mercur mine, but there is no evidence that it formed at the time of the mineralization.

PYRITE.

The analysis of the sulphide ore from the Golden Gate mine shows 6.60 per cent of iron sulphide. So far as has been observed under the microscope, most of this seems to be in very small, dust-like particles, which grade into larger, generally irregular grains, large enough to be recognized. There is no connection between the pyrite and the realgar, and the distribution of the former mineral and its general habit support the belief that the iron was not introduced into the rock at the time of mineralization, but existed previously in the form of disseminated iron oxides, which in turn were chiefly derived from the altered biotite and other iron-bearing silicates of the porphyry. This oxide was probably transformed into the sulphide at the time of the later mineralization.

IMPREGNATION OF THE LIMESTONE.

It is by the characteristics of the realgar that the nature of the mineralization must be judged, since the minerals which accompany it are not abundant enough to admit of careful observation. So far as the observation of the realgar goes, there is no positive evidence that any of it was deposited by a process of molecular substitution for the silica or the calcite. On the other hand, it is often present in grains whose form suggests the filling of preexisting cavities, and it is known that such irregular cavities existed in both the altered porphyry and the limestone, but particularly in the latter.

A section from the Marion mine shows the process by which the altered limestone becomes extremely porous. It is taken from a portion of the rock along a fracture plane, where the silicifying solutions seem to have acted more potently than in the rest of the rock. Near the walls of the fracture the rock has been in large part altered to a typical dark-gray chert; somewhat farther away there has apparently been a complete silicification, but the rock has a light-gray color and the characteristic texture of limestone. Still farther away it has become almost pulverulent, from partial silicification and the leaching out of the calcite which still formed the larger part of the bulk. Here the outlines of Bryozoa can be seen, like those in the unaltered rock. The section is cut from the hard, apparently totally silicified rock, which retains the texture of limestone. Under the microscope it is found to be mainly a fine-grained chert, which still, however, contains small grains of cloudy calcite scattered through it, sometimes irregularly and sometimes segregated into rhombohedra, and plainly residuary. In some parts of the section this calcite has been dissolved out, and the chert is left very full of small, open cavities of irregular shape. It is probable that in cavities formed in this and other ways most of the minerals of the later mineralization were deposited. It may be that some were also deposited by a process of actual substitution, the sulphides replacing the residual lime, and also, possibly, to a small extent the silica, but it is probable that the general process was rather one of impregnation than of replacement.

PROCESS OF MINERALIZATION.

ORIGINAL DEPOSITION AS SULPHIDES.

All of the ores of the gold horizon were originally deposited in the condition that we find them in the unaltered parts of the sulphide ore, as seen in the Golden Gate mine. All stages of the transition from the sulphides to the oxidized ores can be seen in almost every locality where the ores are extensively exposed.

ASCENDING TENDENCY OF AGENTS.

The distribution of the ores with reference to the porphyry sheet, which evidently determined their deposition, shows that the agents which brought about the mineralization were ascending. The locus of greatest mineralization is typically at the lower contact of the porphyry with the limestone, and from this point extends downward into the limestone a few feet, and to a less degree upward into the altered porphyry. It thus forms a continuous bed-like deposit on the lower side of the porphyry, while on the upper contact the rocks are not mineralized, except in places where the mineralization has extended upward through the porphyry and includes a small portion of the limestone immediately above. So slight is the thickness of the porphyry that it is not possible that the ores could have been derived from it by leaching and so carried downward into the limestone. The only explanation is that the mineralizing agents rose from below till they met the sheet of altered porphyry, when they spread out along the under contact and so produced the mineralization. The channels along which they rose were most likely the open vertical fissures. Where these are thickest the mineralization is richer in the normal ore horizon and extends downward farther into the limestone.

NATURE OF THE AGENTS.

In comparing the primary or Silver ledge mineralization with the later or Gold ledge mineralization, it is seen that ores remarkably alike in geological position differ widely in their chemical and physical phenoména. Both have the same form, being bed-like deposits along the lower contact of a thin sheet of porphyry; one lies directly below the other at a distance of only about 100 feet; and in both cases the porphyry and the limestone with which they are associated are the same in age, chemical composition, and structure. Since, therefore, the rocks in which the ores are found can not furnish any explanation of the difference, it must be that it arises from the nature of the agents which accomplished the mineralization. In the Silver ledge the agents were heated waters, like those which have brought about the formation of many other ore deposits; but they were probably derived from the lava itself at the time of consolidation, instead of being surface waters which, having sunk into the ground, came in contact with the heated igneous rock and rose again toward the surface. This hot-spring action is undoubtedly responsible for the existence of a large number of ore deposits, but is not applicable to the silver ores of Mercur. In the gold ores the phenomena are so totally different that the same explanation can not possibly be applied. Either the agents were not heated waters, or they contained in solution entirely different elements derived from other sources. The actual phenomena of the gold ores make the first supposition the more probable of the two.

There is no evidence in the gold ores of any such extensive dissolving and reprecipitation of the elements of the rock as would naturally accompany the passage of a large body of heated water, and as has actually occurred at the horizon of the Silver ledge. The walls of the fissures or sheeted zones, which have been the chief channels for the mineralizing agents, are perfectly straight, and where a fissure has been widened it is by the crumbling of an especially intensely sheeted zone of the rock. There has been no corrosion of the limestone on the sides of these fissures, resulting in the formation of irregular cavities, and no deposition of recrystallized calcite along their walls. In the main ore horizon the same thing is seen. There appears to have been no gangue of calcite or quartz, which accompanied the arsenic and other minerals, although even in the unoxidized ore most of the rock is soft and the pores and interstices are only imperfectly filled with the sulphides. If silica or quartz had been present in the solution, it would have had abundant opportunity to crystallize out in the imperfectly filled interstices, and have afforded a gangue for the realgar, at the same time cementing the rock and making it solid and firm. The mineralizers, therefore, contained neither silica nor lime, nor agents capable of taking these elements into solution.

Arsenic, mercury, and gold are the only elements which it is certain were introduced into the rocks at the time of the later mineralization. In accordance with the derivation of the pyrite which has been suggested, there was probably also free sulphureted hydrogen. The arsenic was deposited as sulphide; the original form of the mercury is not known; and it is not certain what was the form of the gold, although the presence of tellurium in the analyses suggests a telluride. The selective association of these three rare elements, with the exclusion of nearly all of the commoner ones, certainly indicates unusual conditions of deposition. Particularly noticeable in the analyses is the absence of even a trace of lead, copper, antimony, silver, zinc, manganese, nickel, and cobalt, while the iron was probably in the rock before the mineralization. In most metalliferous spring waters some or all of these metals are present. The deposits at Steamboat Springs, in Nevada, which are now being actually formed by hot springs, and which resemble the Mercur gold ores in containing sulphides of arsenic and mercury, together with gold, contain also sulphide of antimony, ferric hydrate, lead sulphide, copper sulphide, and silver, together with traces of zinc, manganese, cobalt, and nickel.[1]

The peculiar phenomena of the gold ores and their difference from the ores of the Silver ledge are explained by the supposition that the mineralizing agents were rather in a gaseous than a liquid condition, or that the ores were pneumatogenic rather than hydatogenic. Mercury and arsenic are the most volatile of metals, metallic mercury volatilizing at ordinary temperatures and metallic arsenic at about 130° C. Schrauf has shown that the sulphide of mercury volatilizes in laboratory experiments at about 237° C., and probably at far lower temperatures in nature; while the sulphide of arsenic is also easily volatile, the process by which most of it is prepared artificially depending on this property. Concerning the volatility of the telluride of gold, not much appears to have been determined; but from the loss of gold from telluride ores when treated by any process which includes heating, it appears to be easily volatile under favorable conditions. These metals would be the first to pass into the state of vapor and the last to be deposited. In this way they might be separated from solutions containing chiefly the more common metals, and they might continue in the gaseous condition under far lower temperatures than indicated above if accompanied by gases capable of absorbing them.

HYDATOGENIC CINNABAR AND REALGAR.

Opposed to the ordinary occurrence of cinnabar and realgar in this region, where the sulphides are apparently mainly pneumatogenic, are certain comparatively rare occurrences where the phenomena are different, and plainly indicate that the minerals were deposited from circulating waters.

Only a single specimen of cinnabar was of this sort. This was taken from a fracture in the Marion mine, and is of the dark-red crystalline variety. There is a plentiful gangue of fine-grained calcite, which fills most of the fracture. In the middle of the specimen a narrow cavity is still left unfilled, and on the sides of this cavity calcite forms small, perfect crystals. Intergrown with the calcite is the crystalline cinnabar, sometimes entirely inclosed in a crystal of calcite, and sometimes coating the outside. Contemporaneous deposition of calcite and cinnabar is thus shown. All other cinnabar found in this district was of the vermilion-colored, earthy kind.

Cases of realgar having this association are more common. At different places, generally outside of the rock which is sufficiently mineralized to be classed as an ore, small veins of granular calcite contain isolated grains of realgar. Judging both from field and microscopical evidence, these grains have crystallized simultaneously with the calcite. But the limestone in which the veins usually occur appears quite

[1] G. F. Becker, Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 343.

fresh, with even its most delicate organic structures uneffaced by any alteration.

These examples of hydatogenic formation indicate a process which is distinct from that which has produced the ores in general, and which has operated only in a feeble manner. It has the appearance of being one of the most recent operations connected with the ores, and is probably to be referred to a later period than the general mineralization. Indeed, the conditions of the present day as they exist in the sulphide ores are probably sufficient to account for these occurrences. Ordinary surface waters percolating through the rock are capable of taking into solution lime from the interstices of the rock and of precipitating it along the fissures as regenerated calcite, and Becker[1] mentions a case where cinnabar has formed on the walls of a drift since its opening. The little cinnabar and realgar that is evidently hydatogenic, therefore, may be derived from the original pneumatogenic sulphides by rearrangement since their deposition, due to percolating waters. It is also very possible that the waters which have produced this result were connected with the original mineralization, and were present in small quantities at the close of that process.

THEORY OF GENESIS.

The part played by gaseous agents in the formation of ores has been but little regarded of late. Considered as a gold deposit, that of Mercur is certainly unusual, for in most deposits the gold has been undoubtedly precipitated from circulating waters; in the typical gold-quartz ore this is beyond a question. Suess,[2] however, considers that vapors may have formed gold deposits, as well as those of the other metals, and it seems probable that the conditions governing the deposition of the telluride of gold are different from those which bring about the concentration of the native metal.

Considered as a mercury deposit, the theories advanced come more in line with previous observation. On account of the extraordinarily easy volatility of mercury, its deposition from a gaseous condition has long been a favorite explanation of its occurrence, and undoubtedly has been often applied to cases where the deposition was actually from waters. Becker has shown that the cinnabar deposits of California, which were long considered as having been partly at least deposited from vapors, are probably derived from ascending heated waters. On the other hand, Professor Schrauf[3] considers that the cinnabar of Idria, in Austria, was deposited mainly from moist vapors. He distinguishes two distinct methods of occurrence, like those which have been noted for the gold ores of Mercur—a primary pneumatogenic deposition, and a later hydatogenic deposition, the former being distinguished by the

[1] Monograph XIII, p. 307.
[2] Die Zukunft des Goldes, Wien, 1877, p. 98.
[3] Jahrbuch k. k. geol. Reichsanstalt, Vol. XLI, 1892, p. 390.

absence of gangue minerals, such as regenerated calcite, and the latter by their presence.

Arsenic is a very common mineral in the vicinity of volcanoes, where it is deposited from the vapors of the fumaroles. Daubrée[1] classes arsenic among the substances characteristic of stanniferous deposits, which are generally considered as of gaseous origin; the other characteristic substances are silica, fluorine, boron, and phosphorus.

A general theory for the deposition of these gold ores may then be formulated as follows:

Subsequent to the introduction of the porphyry and the formation of the silver ores, a comparatively local disturbance brought about the formation of a set of nearly vertical northeast fissures or fractured zones. These fissures established a communication with a body of uncooled igneous rock at an uncertain depth below and afforded a vent for moist volcanic vapors. The decomposition of the Gold ledge sheet of porphyry was already far advanced at the time of the formation of the fissures; these fissures, therefore, did not continue into the porphyry as open channels; the movement produced in the porphyry only a slight rearrangement of the individual grains. In the lowest sheet, however, that of the Silver ledge, the porphyry had become so indurated at the period of the primary mineralization that in only a few cases, in the vicinity of the principal mines, does it show any subsequent softening, due to oxidation; in this hard altered porphyry the fissures are as clean cut as in the limestone. The ascending vapors therefore found no impediment to their progress till they reached the second sheet, but this offered no open passages, and so interposed a blanket-like barrier to further upward motion. The limestone at the lower contact of the porphyry, however, had been partly silicified at the period of primary mineralization, and, in the succeeding period, had been rendered porous by the leaching out of a large part of the residual lime. Along this porous zone the vapors spread out, and, becoming cooled, deposited the gold and the associated minerals; they also penetrated to a small degree upward into the less permeable altered porphyry.

This theory does not dispense with water as a mineralizing agent; indeed, it is most probable that water in the form of steam has played a very important part. Dana remarks that in ordinary volcanic vapors water makes up 99 parts in every 100, and Scrope considered that it composed 999 parts in every 1,000. The solvent power of steam on the more volatile metals is undoubtedly much more powerful than that of even highly heated waters; and this may be held to account in part for the great difference between this and plainly hydatogenic deposits in the proportion of minerals introduced to the rearrangement of the country rock by the accompanying solutions.

---

[1] Géologie expérimentale, Paris, 1879, p. 30.

Fumarolic activity in eruptive rocks is not of slight duration, but often lasts, with little change, through long periods of time. Even at the surface the loss of heat from a lava is surprisingly slow. Scrope mentions the case of a bed of lava at Jorullo, in Mexico, which emitted vapors from fissures till nearly a hundred years after its eruption. When the eruptive rock is buried at even a very slight depth, the length of time that it retains its heat is enormous. Scrope[1] and Lyell[2] both cite the case of the fumaroles at Pozzuoli, near Naples, which were in the same condition in the time of Homer as at present; at the opening of the principal fumarole, Prof. É. de Chancourtois found cinnabar and realgar, which had been deposited from the jet of gases.[3] In Utah, Gilbert has noted[4] fumarolic activity still existing in a cinder cone of Tertiary age; and he judges that this action has been kept up steadily since the formation of the cone. "After most eruptions," says Scrope,[5] "a vast body of heated lava is likely to remain beneath the bottom of the crater, in which the process of solidification goes on slowly for an indefinite and often very long period, affording a continual source of aqueous vapor charged more or less with various mineral substances."

SUMMARY OF GOLD LEDGE GEOLOGY.

What is known as the Gold ledge is a mineralized zone which is developed in the lower part of the Mercur Basin, and mainly on Mercur and Marion hills. This zone is chiefly an altered limestone, and follows the under contact of a thin sheet of porphyry, which is itself so greatly altered as to be often hardly recognizable, and which is situated about 100 feet above the porphyry sheet that is characterized by the phenomena of the Silver ledge. The mineralization of the limestone along the contact of this upper porphyry is not continuous, but varies from nothing up to 15 or 20 feet. The lines of greatest mineralization seem to coincide in direction with a set of nearly vertical northeast fissures, so that the ore forms northeast-trending shoots or channels. The typical form of the ore body therefore has a long northeast axis, a considerably shorter horizontal axis at right angles to the first, and a very short vertical axis.

The ores are divided into two classes, which, however, were originally alike, the oxidized and the sulphide ores. The former are chiefly shown in the Mercur and the Marion mines, and are thus far the only productive ores, since the gold can be extracted from them by leaching with cyanide of potassium; the latter are best developed in the Golden Gate explorations, and can be leached only after roasting.

---

[1] Volcanoes, London, 1872, p. 230.
[2] Principles of Geology, 1872, p. 603.
[3] Mon. U. S. Geol. Survey, Vol. XIII, 1888, p. 36.
[4] Mon. U. S. Geol. Survey, Vol. I, 1890, p. 334.
[5] Op. cit., p. 147.

In the sulphide zone the ores are soft and shale-like, and in the oxidized zone they become partly pulverulent, although in both there is much chert scattered throughout. This softened and altered limestone has a composition which is little like that of the original rock, being chiefly made up of silica of the cryptocrystalline variety. Crystalline quartz is rare. Besides the silica, the ores are characterized by the sulphides of arsenic, iron, and mercury; barite, calcite, gypsum, jarosite, and melanterite are not uncommon, and variscite and rhodochrosite have been found. Scorodite is a characteristic mineral of the oxidized ores, arising from the alteration of the realgar.

The amount of gold in the ores is never very great, rarely exceeding two or three ounces to the ton, and averaging much less. Silver is generally entirely absent. It is probable that the gold exists in the original sulphide ores, as telluride, and that on oxidation it has become free gold.

The mineralization of the Gold ledge probably took place at a distinctly later period than that of the Silver ledge, and the general nature of the phenomena indicates that the agents were gaseous rather than liquid; that they ascended along the open vertical fissures, probably from some uncooled body of igneous rock below, and impregnated the zone at the lower contact of the porphyry sheet, which was already altered and porous from the effects of the earlier Silver ledge mineralization, with arsenic, mercury, and gold.

ECONOMIC GEOLOGY OF THE
MERCUR MINING DISTRICT, UTAH
BY *S. F. EMMONS*

DATE DUE

OCT 1 3 1983

SEP 2 9 REC'D

JAN 2 1985

SEP 1 1986

DEC 2 1 1988

SEP 2 9 2005

MAR 2 2 1989

JUL 2 5 1997

JUL 0 5 1997

OCT 0 3 2005

DEC 0 8 2009

DEC 0 7 2011

DEMCO 38-297